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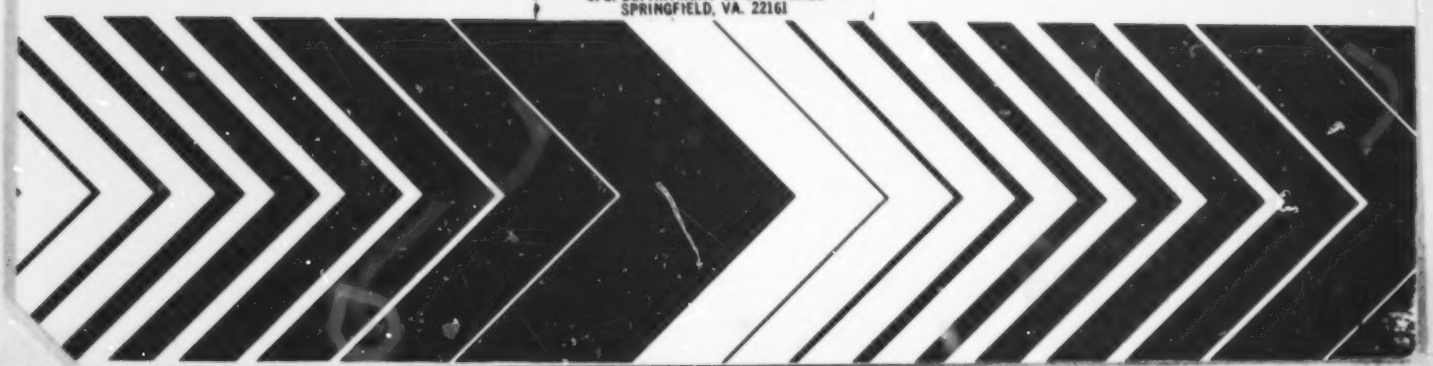

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16. ABSTRACT

This document reviews the state of the art of air emissions from the reclaiming of waste solvents. The composition, quantity, and rate of emissions are described. Waste solvents are organic dissolving agents which are contaminated with suspended and dissolved solids, organics, water, other solvents, and/or other substances. Reclaiming consists of restoring a waste solvent to a condition that permits its reuse. A representative plant was defined in order to determine the potential environmental impact of the solvent reclaiming industry. Source severity was defined as the ratio of the time-averaged maximum ground level concentration of a pollutant to a hazard factor. For criteria pollutants, the hazard factor is the ambient air quality standard; for noncriteria pollutants, it is a reduced TLV. In a representative plant, the hydrocarbon source severity is 0.31, and particulate source severity is 0.0085; for selected solvents ranging from acetone to butanol, source severities ranged from 0.0063 to 0.05. Hydrocarbon emissions are controlled using floating roofs, refrigeration, and conservation vents for storage tanks, and packed scrubbers and secondary condensers for distillation units. Particulate control from incinerator stacks is accomplished using wet scrubbers.

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SOURCE ASSESSMENT:
RECLAIMING OF WASTE SOLVENTS
State of the Art

by

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This report has been reviewed by the Industrial Environmental Research Laboratory-Cincinnati, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report contains an assessment of air emissions from the reclaiming of waste solvents. This study was conducted to provide a better understanding of the distribution and characteristics of emissions from reclaiming operations. Further information on this subject may be obtained from the Organic Chemicals and Products Branch, Industrial Pollution Control Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

PREFACE

The Industrial Environmental Research Laboratory (IERL) of the U.S. Environmental Protection Agency (EPA) has the responsibility for insuring that pollution control technology is available for stationary sources to meet the requirements of the Clean Air Act, the Federal Water Pollution Control Act, and solid waste legislation. If control technology is unavailable, inadequate, or uneconomical, then financial support is provided for the development of the needed control techniques for industrial and extractive process industries. Approaches considered include: process modifications, feedstock modifications, add-on control devices, and complete process substitution. The scale of the control technology programs ranges from bench- to full-scale demonstration plants.

IERL has the responsibility for developing control technology for a large number of operations (greater than 500) in the chemical and related industries. As in any technical program, the first step is to identify the unsolved problems. Each of the industries is to be examined in detail to determine if there is sufficient potential environmental risk to justify the development of control technology by IERL.

Monsanto Research Corporation (MRC) has contracted with EPA to investigate the environmental impact of various industries that represent sources of pollutants in accordance with EPA's responsibility, as outlined above. Dr. Robert C. Binning serves as MRC Program Manager in this overall program, entitled "Source Assessment," which includes the investigation of sources in each of four categories: combustion, organic materials, inorganic materials, and open sources. Dr. Dale A. Denny of the Industrial Processes Division at Research Triangle Park serves as EPA Project Officer for this series. Reports prepared in this program are of two types: Source Assessment Documents and State-of-the-Art Reports.

Source Assessment Documents contain data on pollutants from specific industries. Such data are gathered from the literature, government agencies, and cooperating companies. Sampling and analysis are also performed by the contractor when the available information does not adequately characterize the source pollutants. These documents contain all of the information necessary for IERL to decide whether a need exists to develop additional control technology for specific industries.

State-of-the-Art Reports include data on pollutants from specific industries which are also gathered from the literature, government agencies and cooperating companies. However, no extensive sampling is conducted by the contractor for such industries. Results from such studies are published as State-of-the-Art Reports for potential utility by the government, industry, and others having specific needs and interests.

This study of the reclaiming of waste solvents was conducted for the Organic Chemicals and Products Branch, Industrial Pollution Control Division, IERL-Cincinnati. Mr. Ronald J. Turner served as EPA Task Officer.

ABSTRACT

This document reviews the state of the art of air emissions from the reclaiming of waste solvents. The composition, quantity, and rate of emissions are described.

Waste solvents are organic dissolving agents which are contaminated with suspended and dissolved solids, organics, water, other solvents, and/or any substance not added to the solvent during its manufacture. Reclaiming is the process of restoring a waste solvent to a condition that permits its reuse. Industries that produce waste solvents include solvent refining, vegetable oil extraction, polymerization processes, and cleaning operations. Hydrocarbon and particulate emissions result from the reclaiming of waste solvents. Emission points at solvent reclaiming plants are storage tank vents, condenser vents, incinerator stacks and fugitive losses.

A representative plant was defined in order to determine the source severity of emissions from the solvent reclaiming industry. Source severity was defined as ratio of the maximum ground level concentration of a pollutant divided by a hazard factor. Ambient air quality standards were used as hazard factors for criteria pollutants; modified threshold limit values were used as hazard factors for noncriteria pollutants. A representative plant was found to have a hydrocarbon source severity of 0.31 and a particulate source severity of 0.0085. Using selected solvents as noncriteria pollutants ranging from acetone to butanol, source severities ranged from 0.0063 to 0.05. Approximately 78 persons are affected by air emissions from a representative solvent reclaiming operation in the area surrounding the operation in which the source severity is 0.1 or greater.

Control equipment for hydrocarbon emissions includes floating roofs, refrigeration, and conservation vents for storage tanks, and packed scrubbers and secondary condensers for distillation units. Particulate control from incinerator stacks is accomplished with wet scrubbers.

This report was submitted in partial fulfillment of Contract 68-02-1874 by Monsanto Research Corporation under the sponsorship of the U.S. Environmental Protection Agency.

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ABBREVIATIONS AND SYMBOLS

C	-- diameter factor
Cap	-- production capacity
D	-- tank diameter
e	-- 2.72
E	-- emission factor, g/kg
E'	-- emission factor, lb/ton
F	-- hazard exposure level
F_g	-- equivalent gasoline working loss
F_p	-- paint factor
H	-- effective emission height
H'	-- tank outage
K	-- equilibrium constant
K_T	-- turnover factor
L	-- total petrochemical loss
L_l	-- petrochemical loss
L_y	-- equivalent gasoline breathing loss
M	-- molecular weight of chemical stored
N	-- number of turnovers per year
P	-- vapor pressure of material stored at bulk temperature
Q	-- mass emission rate
S	-- source severity
t	-- averaging time
t_o	-- short-term averaging time
ΔT	-- averaging ambient temperature change
TLV	-- threshold limit value
$\bar{u}$	-- average wind speed
V	-- tank capacity
W	-- liquid density of chemical stored
χ_{max}	-- maximum ground level concentration
$\bar{\chi}$	-- time-averaged ground level concentration
$\bar{\chi}_{max}$	-- time-averaged maximum ground level concentration

CONVERSION FACTORS AND METRIC PREFIXES[a]

CONVERSION FACTORS

To convert from	to	Multiply by
Barrel (bbl, 42 gal)	$Meter^3$	1.590×10^{-1}
Degree Fahrenheit (°F)	Degree Celsius	$t_C^\circ = (t_F^\circ - 32)/1.8$
Degree Celsius (°C)	Degree Fahrenheit	$t_F^\circ = 1.8\ t_C^\circ + 32$
Foot (ft.)	Meter	3.048×10^{-1}
Kilogram (kg)	Pound-mass (lb mass avoirdupois)	2.205
$Kilometer^2$ (km^2)	$Mile^2$	3.860×10^{-1}
Meter (m)	Foot	3.281
$Meter^3$ (m^3)	$Foot^3$	3.531×10^{1}
$Meter^3$ (m^3)	Gallon (U.S. liquid)	2.642×10^{2}
$Meter^3$ (m^3)	Liter (ℓ)	1.000×10^{3}
Metric ton	Pound-mass	2.205×10^{3}
Metric ton	Ton (short, 2,000 lb mass)	1.102
Milliliter (mℓ)	$Meter^3$	1.000×10^{-6}
$Pounds\text{-}force/inch^2$ (psi)	Pascal (Pa)	6.895×10^{3}
Pound-mass (lb mass)	Kilogram	4.536×10^{-1}

METRIC PREFIXES

Prefix	Symbol	Multiplication factor	Example
Kilo	k	10^3	$1\ kg = 1 \times 10^3$ grams
Milli	m	10^{-3}	$1\ mg = 1 \times 10^{-3}$ gram

[a] Standard for Metric Practice. ANSI/ASTM Designation: E 380-76$^\epsilon$, IEEE Std 268-1976, American Society for Testing and Materials, Philadelphia, Pennsylvania, February 1976. 37 pp.

SECTION 1

INTRODUCTION

Organic solvents are used by industry for extractions, for cleaning, and as chemical mediums or intermediates. To meet the variety of industrial needs, solvents are available as halogenated, aliphatic, and aromatic hydrocarbons, as alcohols, esters, glycol ethers, ketones, and nitroparaffins, and as miscellaneous other compounds such as tetrahydrofuran. This classification includes solvents such as methyl ethyl ketone, benzene, perchloroethylene, and isopropanol.

A solvent which is not consumed during industrial use will usually become contaminated and therefore, will be unacceptable for further use. If used solvents are reclaimed, they can be reused for their original purpose or for different industrial needs. The reclaiming of waste solvents has become important since solvent supply and cost are dependent upon the petroleum industry. The rising cost of virgin solvents and the cost of waste solvent disposal have provided an incentive for industry to recover their solvents for reuse.

The purpose of this study is to assess the atmospheric emissions from the reclaiming of waste solvents. The composition, quantity, and rate of emissions are described.

This document is divided into six sections. Section 2 summarizes the major findings of this study. Section 3 provides a detailed description of the solvent reclaiming industry. Section 4 gives data on emissions and provides an assessment of the environmental impact of the source on the basis of source severity and affected population. Section 5 discusses present and future emission control technology for the solvent reclaiming industry. Section 6 relates the growth and nature of the industry.

SECTION 2

SUMMARY

Waste solvents are organic dissolving agents which are contaminated with suspended and dissolved solids, organics, water, other solvents, and/or any substance not added to the solvent during its manufacture. Reclaiming is the process of restoring a waste solvent to a condition that permits its reuse. Reclaiming is accomplished by removing materials that have contaminated the solvent during industrial use. Recovery is another term used to describe the process of restoring a waste solvent for the purpose of reuse.

Industries that produce waste solvents include solvent refining, vegetable oil extraction, polymerization processes, and cleaning operations. From a technological standpoint any solvent can be reclaimed to a point where it can be reused, for an alternative use if not for its original purpose. The limiting factor determining whether a solvent is to be reclaimed is economic. The cost of reclaiming a waste solvent may be higher than the cost of the virgin material.

The process used to reclaim waste solvents has been termed "The General Reclamation Scheme for Solvent Reuse." This process has been broken down into the unit operations of storage and handling, initial treatment, distillation, purification, and waste disposal. The total amount of solvent reclaimed by this process is estimated to be 103.7×10^6 metric ton/yr[a].

Hydrocarbon and particulate emissions result from the reclaiming of waste solvents. Noncriteria pollutants include any solvent being reclaimed by a particular plant. Emission points from plants reclaiming waste solvents are storage tank vents, condenser vents, incinerator stacks, and fugitive losses.

A representative plant was defined in order to determine the severity of emissions from the solvent reclaiming industry. Plant parameters used in determining a representative plant include production capacity, population density, and emission heights. These data were taken from information on the reclaiming of waste solvents by private contractors.

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[a] 1 metric ton = 10^6 grams; conversion factors and metric system prefixes are presented in the prefatory pages of this report.

Parameters used to assess the impact of the solvent reclaiming industry include source severity, state and national emission contributions, and affected population.

Source severity has been defined as the maximum ground level concentration divided by a hazard factor. The ground level concentration is determined by Gaussian plume methodology, and ambient air quality standards are used to represent hazard factors for criteria pollutants. Modified threshold limit values are used to determine hazard factors for noncriteria pollutants. A representative plant was found to have a hydrocarbon source severity of 0.31 and a source severity for particulates of 0.0085. Using selected solvents as noncriteria pollutants ranging from acetone to butanol, source severities ranged from 0.0063 to 0.05.

Emissions from solvent reclaiming plants on a national scale were found to total 218,000 metric ton/yr for hydrocarbons and 73,000 metric tons/yr for particulates. This accounts for 0.87% and 0.41% respectively, of the total national emissions from stationary sources.

Kentucky was the only state where hydrocarbon emissions from reclaiming operations contributed greater than 0.01% of the state's total hydrocarbon emissions. Solvent reclaiming operations contributed 0.001% or less of total particulate emissions for any one state.

The area affected by a source severity of 0.1 from solvent reclaiming operations has been calculated to be 0.12 km^2. Population densities for plants of private contractors ranged from 24 persons/km^2 to 2,223 persons/km^2, with a mean value of 653 persons/km^2. Thus the affected population for a representative solvent reclaiming operation is 78 persons.

The rate of growth for private contractors reclaiming waste solvents is a 5% annual increase in the amount of solvent reclaimed. Using this percent increase, the total increase of hydrocarbon emissions from 1977 through 1980 has been calculated to be 0.03% or 59 metric tons.

Control equipment for hydrocarbon emissions includes floating roofs, refrigeration, conservation vents for storage tanks, packed scrubbers, and secondary condensers for distillation units. Control of particulates from incinerator stacks is accomplished with wet scrubbers.

Fugitive emissions are a major source of emissions, comprising at least 21% of the total hydrocarbon emission factor. Control of fugitive emissions is accomplished by proper plant maintenance, by improved loading procedures such as submerged filling, and by reducing the number of solvent sources open to the atmosphere.

SECTION 3

SOURCE DESCRIPTION

The reclaiming of solvents is accomplished by industry as a main process by private contractors, as an integral part of a main process such as solvent refining, or as an add-on process seen in the surface coating and cleaning industries. Table 1 (1-9) identifies industries that reclaim solvents and the type and

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(1) 1976 Refining Process Handbook. Hydrocarbon Processing, 55(9):189-230, 1976.

(2) Cantrell, A. Annual Refining Survey. The Oil and Gas Journal, 74(13):124-156, 1976.

(3) Kirk-Othmer Encyclopedia of Chemical Technology, Second Edition, Vol. 18. John Wiley & Sons, Inc., New York, New York, 1969. pp. 549-563.

(4) Formica, P. N. Controlled and Uncontrolled Emission Rates and Applicable Limitations for Eighty Processes. Contract 68-02-1382, Task, 12, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, September 1976. pp. V-43/V-46.

(5) Kirk-Othmer Encyclopedia of Chemical Technology, Second Edition, Vol. 8. John Wiley & Sons, Inc., New York, New York, 1965. pp. 796-797.

(6) Shreve, R. N. The Chemical Process Industries, Third Edition. McGraw-Hill Book Company, Inc., New York, New York, 1969. pp. 876-879.

(7) Kirk-Othmer Encyclopedia of Chemical Technology, Second Edition, Vol. 14. John Wiley & Sons, Inc., New York, New York, 1969. pp. 695-697.

(8) Kirk-Othmer Encyclopedia of Chemical Technology, Second Edition, Vol. 7. John Wiley & Sons, Inc., New York, New York, 1965. pp. 307-309.

(9) Scofield, F., J. Levin, G. Beeland, and T. Laird. Assessment of Industrial Hazardous Waste Practices, Paint and Allied Products Industry, Contract Solvent Reclaiming Operations, and Factory Application of Coatings. EPA/530/SW-119c, U.S. Environmental Protection Agency, Washington, D.C., September 1975. pp. 189-220.

TABLE 1. DISTRIBUTION OF U.S. SOLVENT RECOVERED BY INDUSTRY[a] (10^3 metric tons/yr)

Solvent	Solvent refining (1, 2)	Polymerization processes (3, 4)	Vegetable oil manufacture (3, 5, 6)	Metallurgical operations (3)	Pharmaceutical manufacture (3, 6, 7)	Cleaning operations (3, 8)	Solvent reclaimers (private contractors) (9)	Other industries
Halogenated hydrocarbons								
Carbon tetrachloride								
Fluorocarbons	[b]					[b]	[b]	
Methylene chloride						180[c]	[b]	
Perchloroethylene						[b]	[b]	
Trichloroethylene						[b]	[b]	
1,1,1-Trichloroethane								
Hydrocarbons								
Hexane		[b]	[b]				[b]	
Benzene	[b]	[b]					[b]	
Toluene	[b]						[b]	
Xylene							[b]	
Cyclohexane		73[c]					[b]	
Ethers							[b]	
Mineral spirits							[b]	
Naphthas			[b]					
Ketones								
Acetone	[b]						[b]	
Methyl ethyl ketone	[b]						[b]	
Methyl isobutyl ketone	[b]				[b]		[b]	
Cyclohexanone								
Alcohols								
Methanol					[b]		[b]	
Ethanol							[b]	
Isopropanol					[b]		[b]	
Butyl alcohol							[b]	
Amyl alcohol								
Esters								
Amyl, butyl, ethyl acetates					[b]		[b]	
Others	[b]			[b]			[b]	
TOTAL	92,000[c]	250[c]	9,100[c]		23[c]	2,100[c]	190	

[a] Blanks indicate data not available.

[b] Particular solvent is reclaimed but quantity is unknown.

[c] MRC estimates.

amount of solvent recovered by each. Table 2 (1-4, 8-11) gives the amount of solvent recovered by specific source and the number of plants recovering solvent by industry. It is estimated that these industries account for more than 80% of all solvent recovered by industrial sources in the United States.

TABLE 2. SOLVENT RECLAMATION BY INDUSTRY[a]

Source	Number of plants (2, 9-11)	Percent of total plants reclaiming solvents	Amount of solvent reclaimed (1-4, 8) 10^3 metric ton/yr	Weight percent
Solvent refining	43[b]	0.21	92,000[b]	88.8
Polymerization processes	19[b]	0.09	250[b]	0.2
Vegetable oil manufacture	240[b]	1.2	9,100	8.8
Metallurgical operations				
Pharmaceutical manufacture	22[b]	0.11	23[b]	0.02
Cleaning operations	20,160[b]	97.89	2,100	2.0
Private contractors	110[b]	0.5	190[a]	0.18
TOTAL	20,594[b]	100	103,663[b]	100

[a]Blanks indicate data not available.

[b]MRC estimates.

In solvent refining, lube oils and waxes are prepared by solvent extraction (1). After extraction, solvent is reclaimed and reused in the refining process. The manufacture of high-density polyethylene and polypropylene utilizes solvents as chemical mediums (3, 4). After polymerization, solvents are reclaimed and recycled back to the polymerization process. Vegetable oil manufacture, metallurgical operations, and pharmaceutical manufacture utilize solvents for extraction purposes and then reclaim them for reuse in the main process (6, 12). Cleaning operations include drycleaning and degreasing of metal (3). Private contractors reclaim solvents from any industry that produces waste solvents from solvent usage. The companies in this field can differ greatly one from another, not only in the waste solvents they process and resell, but also in their self-images. The field is shared by such different companies as those who consider themselves to be specialty chemical manufacturers and use waste solvents as part of their raw material inputs; by companies who only buy waste solvents for direct sale to others with or without

(10) 1972 Census of Manufacturers, Industry Series (SIC Industry Group 207), Fats and Oils. MC72(2)-20G, U.S. Department of Commerce, Washington, D.C., January 1975. 38 pp.

(11) Suprenant, K. S., and D. W. Richards. New Source Performance Study to Support Standards for Solvent Metal Cleaning Operations, Appendix Reports (Appendix A). Contract 68-02-1329, U.S. Environmental Protection Agency, Durham, North Carolina, June 30, 1976. 87 pp.

(12) Clegg, J. W., and D. D. Foley. Uranium Ore Processing. Addison-Wesley Publishing Company, Inc., Reading, Massachusetts, 1958. 437 pp.

processing; and by companies who process a variety of materials, sell what is marketable, and handle their own final disposal problems through incineration and landfill. Solvent use and reclamation by other operations such as the coating industry are covered in Table 1 under "Other Industries."

The solvent reclaiming process is described by the unit operations shown in Figure 1, General Reclamation Scheme for Solvent Reuse. All solvent recovery operations are included under this process description.

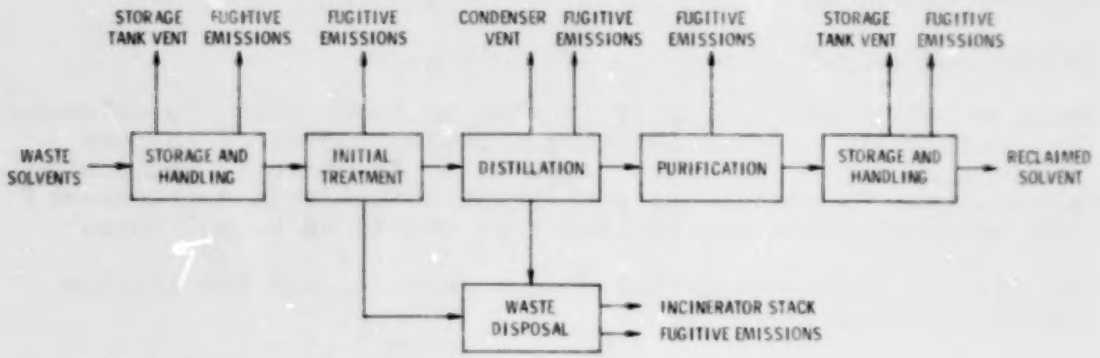

Figure 1. General reclamation scheme for solvent reuse.

Methods employed in each unit operation are described in this section. Criteria determining which methods are appropriate in reclaiming a particular waste solvent are provided in the description of each unit operation.

PROCESS DESCRIPTION

Solvent Storage and Handling

Solvents are stored before and after reclamation. For example, private contractors reclaim solvents from various industries such as paint manufacturers and degreasing operations. The solvents are transported from the industrial site, in tank cars and drums, to the reclaiming plant, where they are recovered and then returned to the site or sold to another plant for reuse. This procedure involves continuous storage and handling since solvent must be loaded on and off tank cars and trucks and stored until processing time is available.

Solvents are stored in containers ranging in size from 0.208 m^3 (55-gal) drums to tanks with capacities of 75 m^3 (20,000 gal) or more. Storage tanks are of fixed or floating roof design. Fixed-roof tanks are metal cylinders or boxes of rigid construction. Venting systems are used to prevent solvent vapors from creating excessive pressure inside the tanks. Floating-roof

tanks have movable tops which float on the surface of the contained solvent while forming an airtight seal with the tank walls (13).

The handling of solvent includes the loading of waste solvent into process equipment and the filling of drums and tanks prior to transport and storage. Filling of tanks and drums is done through splash or subsurface loading (14). Splash loading is the filling of the tank or drum from the top, allowing solvent to fall free to the bottom of the container. Subsurface filling is accomplished by pumping the solvent into the bottom of the solvent container.

Initial Treatment

Waste solvents are initially treated by vapor recovery or mechanical separation. Vapor recovery entails removal of solvent vapors from a gas stream in preparation for further reclaiming operations. In mechanical separation undissolved contaminants such as metal fines are removed from liquid waste solvents.

The initial treatment method chosen depends upon the factors listed in Table 3 (15).

TABLE 3. FACTORS DETERMINING THE SUITABILITY OF INITIAL TREATMENT METHODS (15)

Waste solvent vapor
• solvent vapor composition
• air concentration of gas stream
• solvent boiling point
• solvent reactivity
• gas stream composition
• solvent vapor concentration
• solvent solubility
Liquid waste solvent
• solvent miscibility
• solids content of waste solvent

(13) Chemical Engineers' Handbook, Fifth Edition. J. H. Perry and C. H. Chilton, eds. McGraw-Hill Book Company, New York, New York, 1973.

(14) Wachter, R. A., T. R. Blackwood, and P. K. Chalekode. Study to Determine Need for Standards of Performance for New Sources of Waste Solvents and Solvent Reclaiming. Contract 68-02-1411, Task 15, U.S. Environmental Protection Agency Research Triangle Park, North Carolina, February 1977. 106 pp.

(15) Drew, J. W. Design for solvent Recovery. Chemical Engineering Progress, 71(2):92-99, 1975.

Absorption, adsorption, and condensation are initial treatment techniques used for collecting solvent vapors from gas streams (16). The technique most suitable for recovering a particular solvent vapor is determined by the factors listed in Table 3 under waste solvent vapor. Industries which make use of vapor recovery systems include magnetic tape production and rubber manufacture (17, 18).

Condensation of solvent vapors is accomplished by water-cooled condensers and refrigeration units. Condensers are capable of reaching temperatures of 15°C, while refrigeration units go as low as 10°C (16). The feasibility of condensation for vapor recovery is dependent upon solvent concentration and the temperature required for condensation. For adequate recovery, solvent components must be above the saturation concentration at the condensing temperature. A solvent vapor concentration well above 20 mg/m^3 is required for effective recovery of solvent vapors by condensation (19).

To avoid explosive mixtures of solvent and air in the process gas stream, air is replaced with an inert gas such as nitrogen. Solvent vapors which escape condensation are recycled through the main process stream or recovered by further initial treatment with adsorption or absorption.

Solvent vapors are also recovered by adsorption on activated carbon. Process gas streams are passed through a bed of activated carbon where solvent vapors are adsorbed. When solvent concentrations in the carbon bed approach saturation level, the gas stream is directed to a second bed, and the first bed is regenerated with live steam. A vapor mixture of solvent and steam is condensed and sent to further recovery processing (19).

Activated carbon adsorption systems are capable of recovering solvent vapors in concentrations below 4 mg/m^3 of air (19). If solvent vapor concentrations are above 20 mg/m^3 of air, preliminary recovery of solvent by condensation is used to allow a maximum amount of solvent-laden air to pass through the carbon

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(16) Scheflan, L., and M. B. Jacobs. The Handbook of Solvents. D. Van Nostrand Company, Inc., New York, New York, 1953. 728 pp.

(17) Solvent Recovery System Proves a Speedy Payout. Rubber World, 165(5):44, 1972.

(18) Reynen, F., and K. L. Kunel. Solvent Recovery System Nets Plant Approximately $50,000/yr Savings. Chemical Processing 38(9):9, 1975.

(19) Darvin, R. L. Recovery and Reuse of Organic Ink Solvents. C and I Birdler, Inc., Louisville, Kentucky, September 1975. 25 pp.

bed before desorption is necessary. Two factors that affect the technical feasibility of recovering solvent vapors are the molecular weight and boiling point of the solvent. Activated carbon will not recover solvents having a molecular weight of less than 30 from air streams (20). Also, solvents with boiling points of 200°C or more do not desorb effectively from activated carbon with low pressure steam (20).

Absorption of solvent vapors by a liquid medium provides an alternative to adsorption schemes. The waste gas stream is passed through a liquid by means of scrubbing towers or spray chambers. Mineral oils have been used as absorbing liquids (16). Solvent vapors from oil seed extraction processes have been recovered by absorption (21).

The effectiveness of solvent recovery by absorption is dependent upon the solubility of the solvent vapor in the absorbing liquid. Solubility is expressed in the form of an equilibrium constant (K) which equals the mole fraction of the solvent in the gas phase divided by the mole fraction of solvent in the liquid phase. K will vary with changes in temperature, pressure and composition of the solvent and absorbing liquid (13).

Further reclaiming procedures are required after solvent vapors are collected by condensation, adsorption or absorption. Recovery of solvent by condensation and adsorption results in a mixture of water and liquid solvent. Absorption recovery results in a mixture of oil and solvent. Both mixtures are ready for further reclaiming by distillation.

Distillation is not necessary if recovered solvent mixtures can be reused without separation and the solvents are immiscible in water (22). In this case solvent-water mixtures are sent directly to purification where the water is removed and the solvent is prepared for reuse (23).

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(20) Enneking, J. C. Control Vapor Emissions by Adsorption. Union Carbide Corporation, New York, New York, 1973. 6 pp.

(21) Oil Absorption System for Vent Solvent Recovery. Engineering Management, Inc., Park Ridge, Illinois. 1 p.

(22) Pickett, G. E., J. A. Jacomet, and L. J. Nowacki. Disposition of Organic Solvents Recovered in Carbon Adsorption Systems in the Industrial Surface Coatings Industry. Contract 68-01-3159, Task 5, U.S. Environmental Protection Agency, Cincinnati, Ohio, December 1976. 43 pp.

(23) Solvent Loss by Evaporation Cut 95% by Recovery System. Chemical Processing, 38(1):25, 1975.

Undissolved solids and water are removed from liquid waste solvents by initial treatment through mechanical separation. This means of separating water from solvent is feasible if the solvent is immiscible in water. Methods for mechanical separation include decanting, filtering, draining, settling, and use of a centrifuge. Decanting is used to separate water from immiscible solvent, while the other methods are used to remove undissolved solids from the waste solvent. A simple cone tank used for settling out solids from waste solvent is shown in Figure 2.

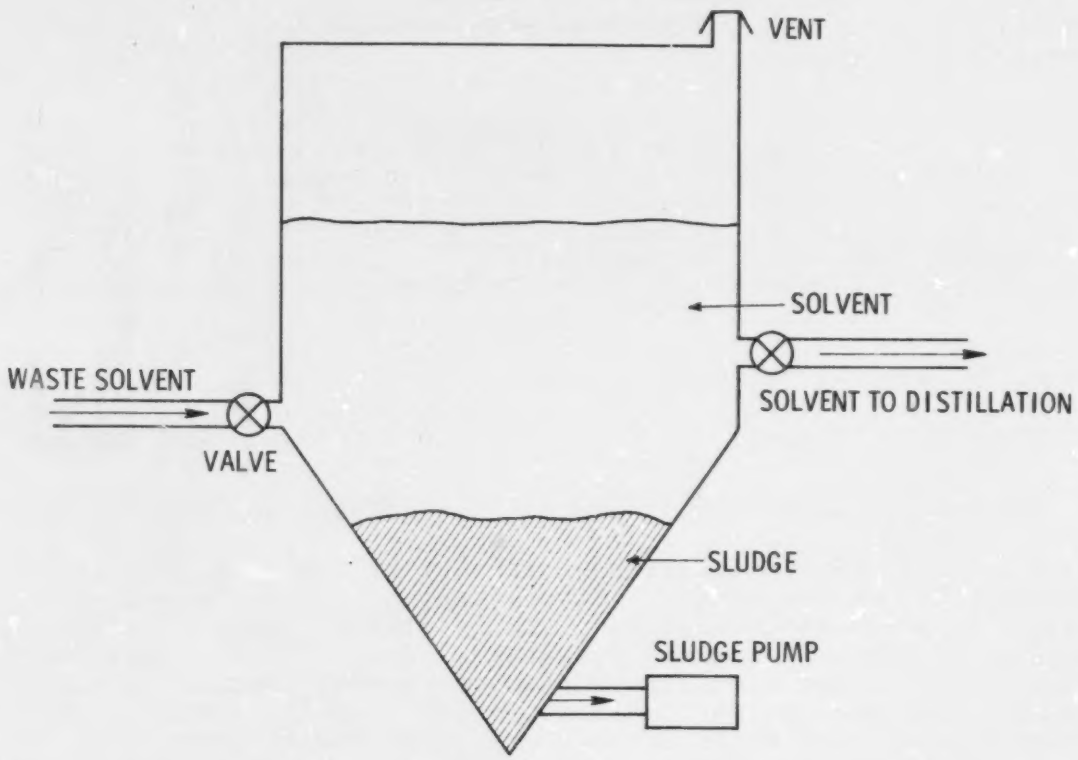

Figure 2. Cone settling tank for removal of undissolved solids from waste solvent.

A combination of initial treatment methods may be necessary to prepare a waste solvent for further processing. For example, a contaminated liquid solvent is filtered to remove undissolved solids and then decanted to remove water before distillation. In another instance solvent vapors are recovered by adsorption and the resulting liquid solvent is decanted to remove water before separation of the solvent mixture by distillation.

Distillation

After initial treatment, waste solvents are distilled to separate solvent mixtures and to remove dissolved impurities (24). Details of the distillation unit operation are shown in Figure 3. Waste solvents are distilled by one of the five distillation methods listed below (13):

- Simple batch distillation
- Simple continuous distillation
- Steam distillation
- Batch rectification
- Continuous rectification

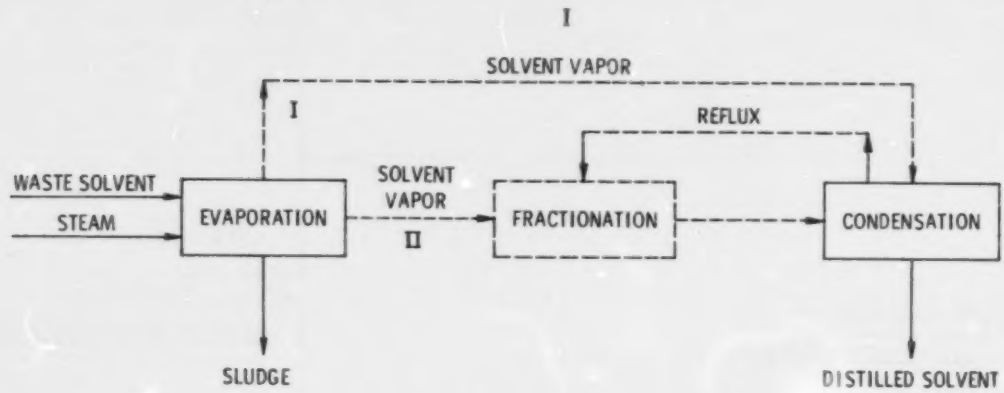

Figure 3. Distillation process for solvent reclaiming (9).

In simple batch distillation a quantity of waste solvent is charged to the evaporator. After charging, vapors are continuously removed and condensed. The resulting sludge or still bottom is removed from the evaporator after solvent evaporation. Simple continuous distillation is the same as batch distillation except that solvent is continuously fed to the evaporator during distillation, and still bottoms are continuously drawn off. In steam distillation solvents are vaporized by direct contact with steam which is injected into the evaporator. Batch, continuous, and steam distillations follow path I of the distillation process shown in Figure 3. These three methods are suitable for separating solvents from their dissolved contaminants.

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(24) Solvent Recovery and Pollution Control Using Industrial Distillation Equipment. No. FB-118, Hoffman Filtration Systems, New York, New York, 1974. 32 pp.

The separation of mixed solvents requires multiple simple distillations or rectification. Batch and continuous rectification are represented by path II in Figure 3. I batch rectification, solvent vapors pass through a fractionating column where they contact condensed solvent (reflux) entering at the top of the column. Solvent not returned as reflux is drawn off as overhead product. In continuous rectification, the waste solvent feed enters continuously at an intermediate point in the column. The more volatile solvents are drawn off at the top of the column while higher boiling point solvents collect at the bottom.

Design criteria for evaporating vessels depend upon waste solvent composition. Resinous or viscous contaminants can coat heat transfer surfaces, resulting in a loss of evaporator efficiency. Evaporators with heating coils exposed to waste solvent are only suitable for solvents with less than 5% solids content (9). Two evaporators that prevent contaminants from fouling heating surfaces are of the scraped surface or thin-film design. In the scraped-surface type, rotating scrapers keep contaminants from adhering to the heated evaporator walls. For heat sensitive or viscous materials thin-film evaporators are the most suitable (25). With this design, solvent is forced into a thin film along the heated evaporator walls by rotating blades. These blades agitate the solvent while maintaining a small clearance from the evaporator walls to prevent contaminant buildup on heating surfaces. Figure 4 shows a typical thin-film evaporator.

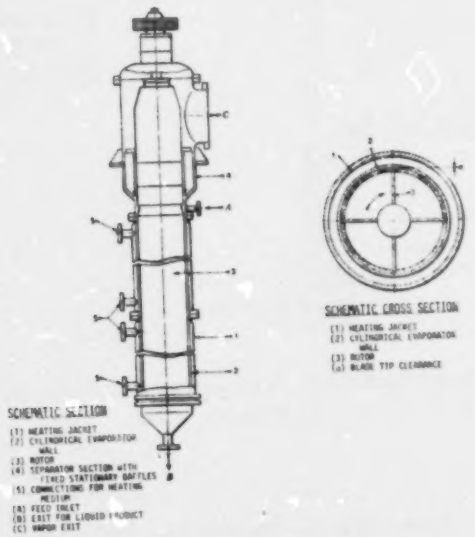

Figure 4. Thin-film evaporator (25).

(25) Reay, W. H. Recent Advances in Thin-Film Evaporation. Luwa (U.K.)Ltd., London, England (reprinted from The Industrial Chemist, June 1963). 5 pp.

Condensation of solvent vapors during distillation is accomplished by shell and tube or barometric condensers. The shell and tube design consists of parallel tubes running through a cylindrical shell. Condensation of solvent is accomplished by the flow of cooling water through the tubes, which are in contact with solvent vapors in the shell. This arrangement prevents the mixing of reclaimed solvent and cooling water. In barometric condensers vapor is condensed by rising against a rain of cooling water (13). Condensation of vapor results in a mixture of solvent and cooling water. A barometric condenser is pictured in Figure 5 (26, 27).

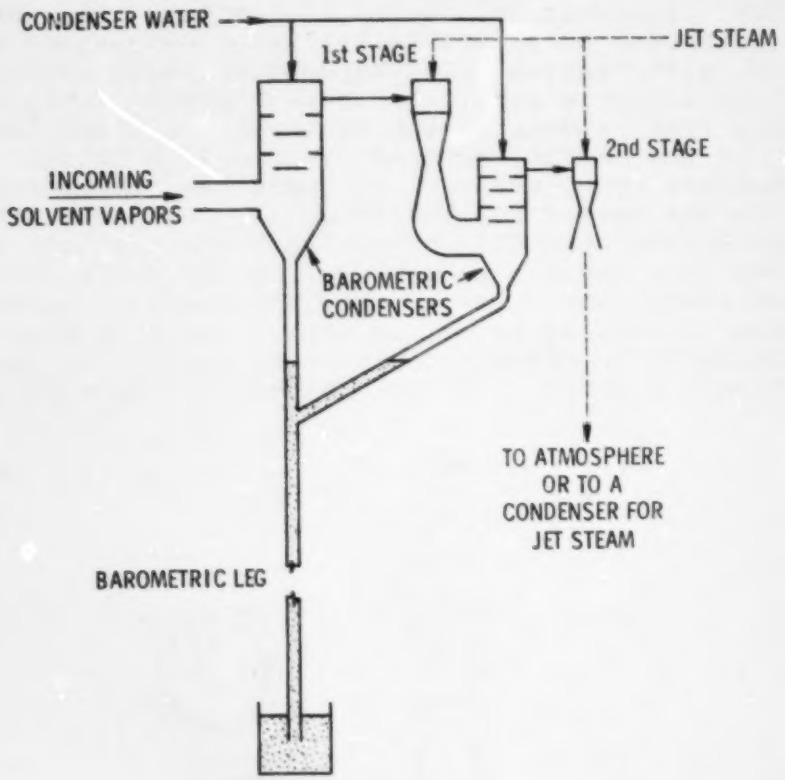

Figure 5. Barometric condenser with steam ejector for distillation (26, 27).

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(26) Nelson, W. L. Petroleum Refinery Engineering, Fourth Edition. McGraw-Hill Book Company, New York, New York, 1958. pp. 252-261.

(27) Nelson, W. L. Questions on Technology: Noncondensable Gases Handled During Vacuum Distillation. The Oil and Gas Journal, 49:100, April 1951.

Azeotropic solvent mixtures are separated during distillation by the addition of a third solvent component. For example, the addition of phenol to cyclohexane-benzene mixtures during distillation causes the activity coefficients for cyclohexane to be nearly twice as large as those for benzene (13). This factor causes the volatility of cyclohexane to be nearly twice that of benzene, allowing for their separation by distillation.

Operating conditions for distillation are dependent upon the particular waste solvent and its desired purity after reclamation. Solvents with boiling points in the range of high flash naphthas (155°C) are most effectively distilled under vacuum (24). Its use reduces heating requirements since the solvent boiling point is lowered by vacuum conditions in the evaporator. A vacuum can be achieved by vacuum pumps or steam ejectors. Distillation rate must be carefully controlled if contaminants are not to be carried over into the condenser. Temperature control is also necessary since excessive heat can chemically alter the original solvent composition. Purity requirements for the reclaimed solvent will determine the number of distillations needed, reflux ratios, and processing time.

Purification

After distillation, water is removed from solvent by decanting or salting. Decanting is accomplished with immiscible solvent and water which, when condensed, form separate liquid layers, one or the other of which can be drawn off mechanically. Additional cooling of the solvent-water mix before decanting increases the separation of the two components by reducing their solubility. In salting, solvent is passed through a calcium chloride bed where water is removed by absorption.

During purification reclaimed solvents are stabilized if necessary. Buffers are added to virgin solvents to insure that pH is kept constant during use. Reclaiming the solvent may cause a loss of buffering capacity. To renew it, special additives are used during purification. The composition of these additives is considered proprietary.

Waste Disposal

Waste materials separated from solvents during initial treatment and distillation are disposed of by incineration, landfilling or deep-well injection. The composition of the waste material will vary depending on the original use of the solvent. Up to 50% of waste material from the reclaiming process will be unreclaimed solvent. Not distilling all of the solvent from the waste enables it to remain in a viscous yet liquid form, facilitating pumping and handling procedures. The following components are present in the waste from solvent reclaiming:

- oils
- greases
- waxes
- detergents
- pigments
- metal fines
- dissolved metals
- organics
- vegetable fibers
- resins

A chemical analysis of specific wastes is given in Table 4. These samples were taken from a presurvey study of a private contractor who reclaims waste solvents.

TABLE 4. ANALYSIS OF SLUDGE FROM SOLVENT RECLAIMING BY PRIVATE CONTRACTORS[a]

Percent unreclaimed solvent	Percent composition of selected elements																			
	Al	Ba	B	Ca	Cd	Co	Cr	Fe	Mg	Mn	Na	Pb	Sb	Si	Sn	Sr	Ti	V	Zn	P	Mo
43	1.1	2.0	0.02	0.29	0.003	0.04	0.15	2.7	2.7	0.007	0.20	3.3	0.05	0.02	0.08	0.05	23	0.03	0.38	0.06	0.06

[a]Data obtained from presurvey sampling.

Incinerators capable of burning liquid wastes are used to dispose of waste from solvent reclaiming operations. Figure 6 (28) shows such an incinerator design. It is estimated that 80% of the waste from solvent reclaiming by private contractors is disposed of in this manner (9).

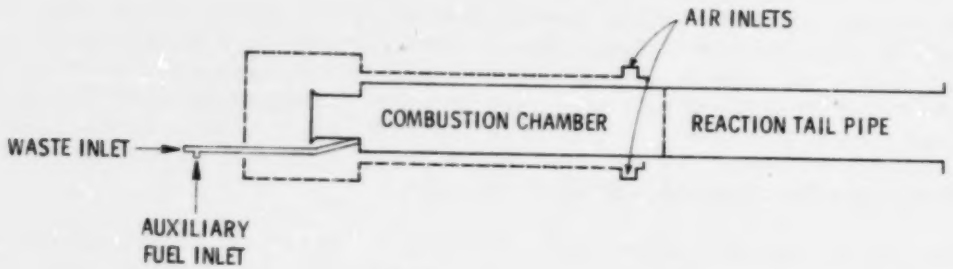

Figure 6. Incinerator for liquid waste disposal (28).

Wastes are also disposed of by landfill deposition. Drums containing solvent reclaiming wastes are dumped into the landfill. Waste not contained in drums can be applied directly to the site.

Deep-well injection is used to dispose of reclaiming wastes if injection sites are available. Wastes are injected between impermeable geologic strata. Dilution of viscous wastes may be necessary for pumping them to the desired strata level.

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(28) Clausen, J. R., R. J. Johnson, and C. A. Zee. Destroying Chemical Wastes in Commercial Scale Incinerators, Facility Report No. 1. Contract 68-01-2966, U.S. Environmental Protection Agency, Washington, D.C., October 1976. 116 pp.

Industrial operations are capable of reclaiming their waste solvents without incorporating all unit operations shown in Figure 1. If solvent reclamation is part of a main process, storage and handling of solvent during recovery is avoided since solvent is continuously reclaimed and fed back into the main process directly through pipes and/or pumps. Initial treatment is not necessary if liquid waste solvents contain no undissolved contaminants. Distillation can be avoided if solvent vapors consist of only one water immiscible solvent. These one-component vapors are collected, liquefied, purified, and reused without distillation. Examples are given in Figures 7 and 8. Figure 7 shows the reclaiming of hexane without the need for storage and handling of solvent during recovery (3). Figure 8 shows the reclaiming of single-component ink solvent vapors by carbon adsorption without the need for distillation (19).

The unit operations described in this section (storage and handling, initial treatment, distillation, and purification) are shown in Figure 9 (29). In this figure a typical solvent reclaiming process is being operated by a private contractor. Figure 10 illustrates distillation and purification operations of a solvent reclaiming system utilizing thermal fluid for evaporation (30, 31).

MATERIALS FLOW

A simple material balance for a plant reclaiming 5,000 metric tons/yr of solvent is shown in Figure 11. The legend indicates the percent of total hydrocarbons emitted by each process operation. These percentages were estimated from emission factors shown in Section 4.

GEOGRAPHICAL DISTRIBUTION

The number of cleaning operations reclaiming waste solvents outnumber other solvent reclaiming operations by a factor of 40. More than 80% of cleaning operations reclaiming waste solvents are drycleaning plants whose geographical locations are population sensitive (8). The remaining cleaning operations are metal degreasing plants. Their distribution and the distribution of

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(29) Brighton Solvent Reclaiming Systems. Bulletin No. RS-4, Brighton Corporation, Cincinnati, Ohio. 6 pp.

(30) System Strips Solvents, Separates Solids Simultaneously. Chemical Engineering, 83(25):93-94, 1976.

(31) Continuous Purification of Waste Solvents. Chemical Processing (London), 20(1):17, 1974.

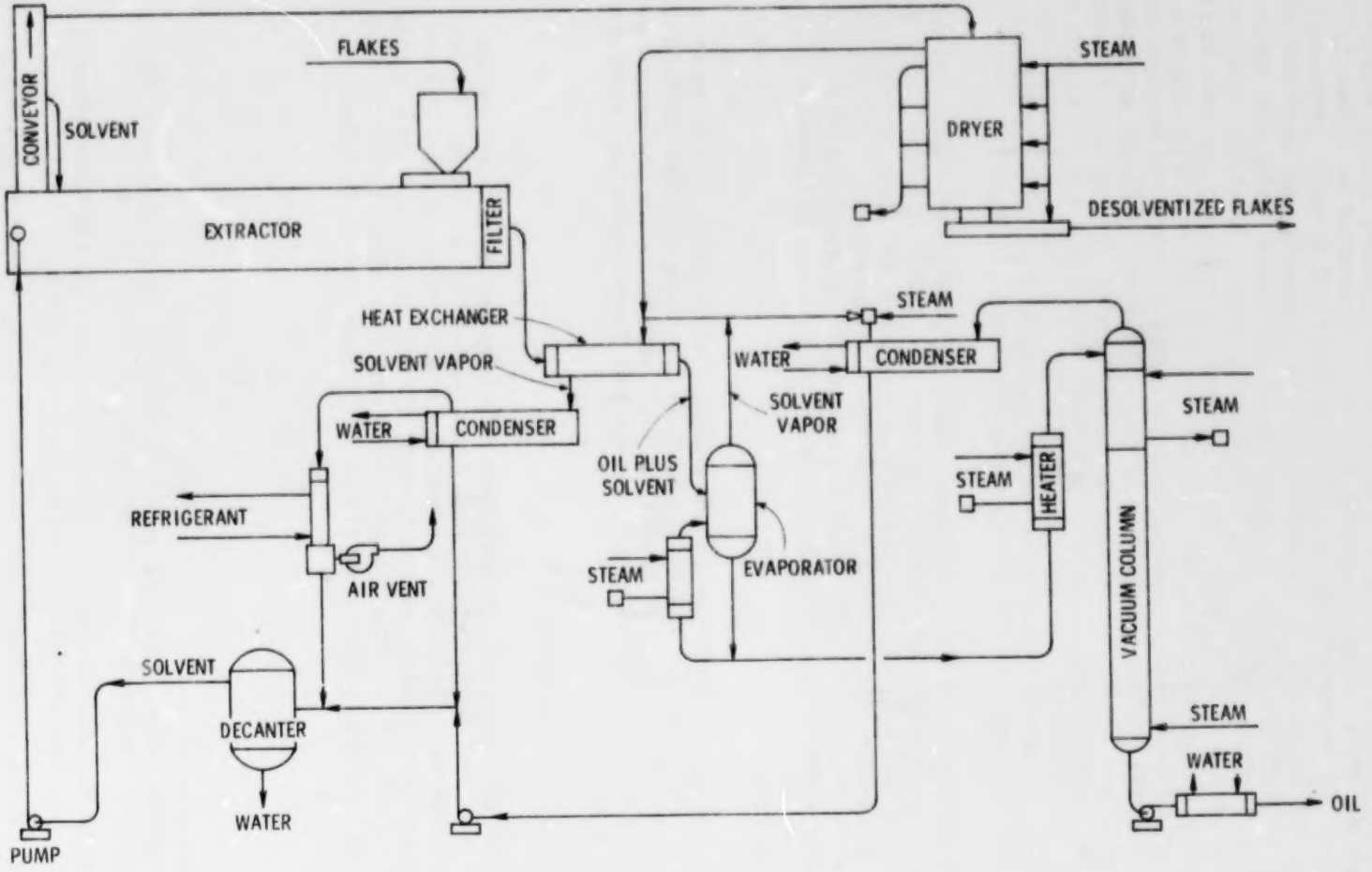


Figure 7. Reclaiming of solvent from vegetable oil extraction with direct feedback to main process (3).

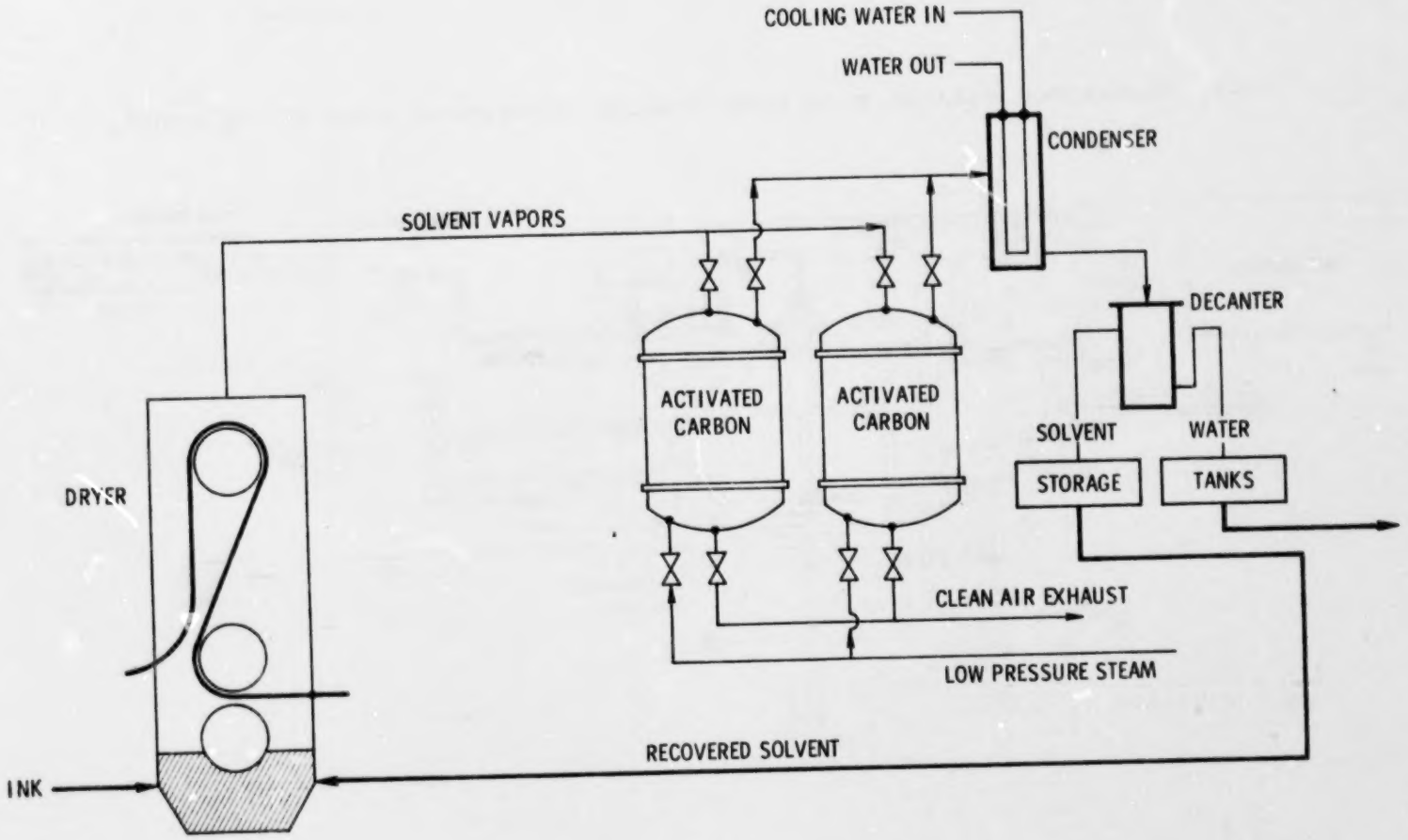


Figure 8. Reclaiming of single-component ink solvent without distillation (19).

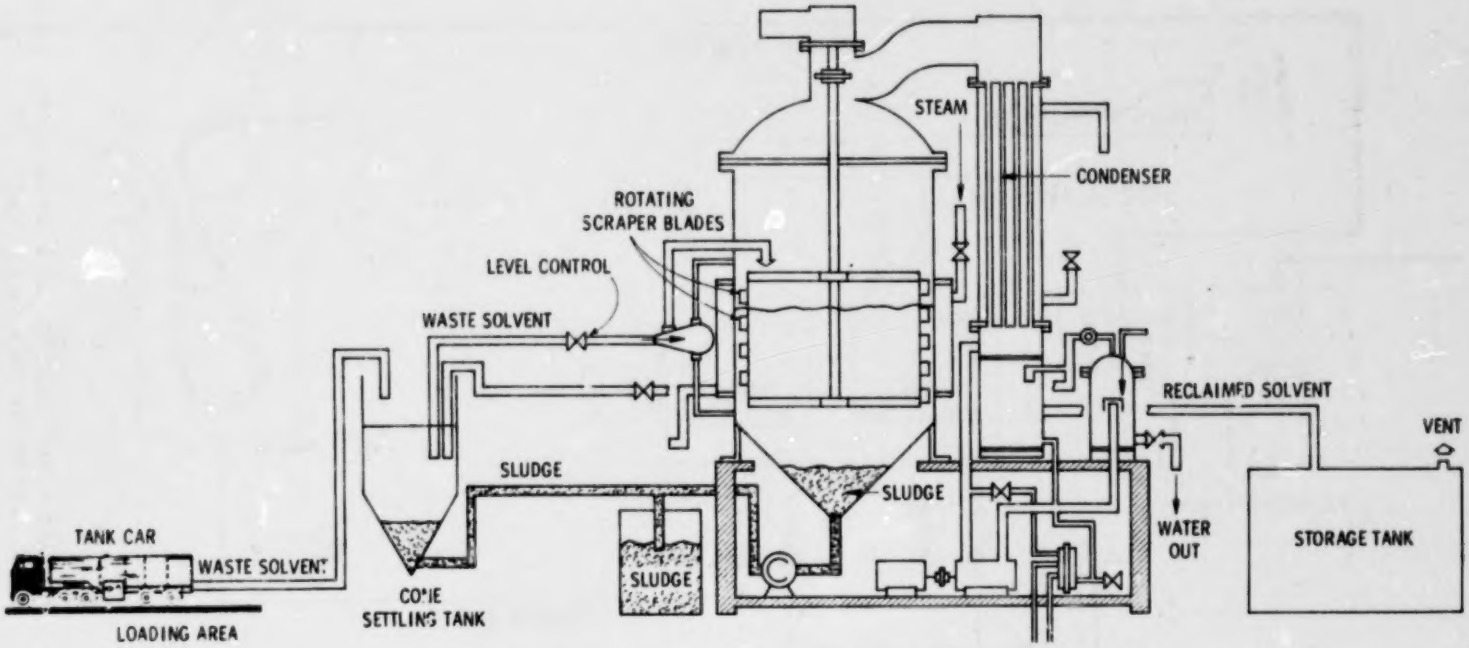


Figure 9. Solvent reclaiming process used by a private contractor (29).

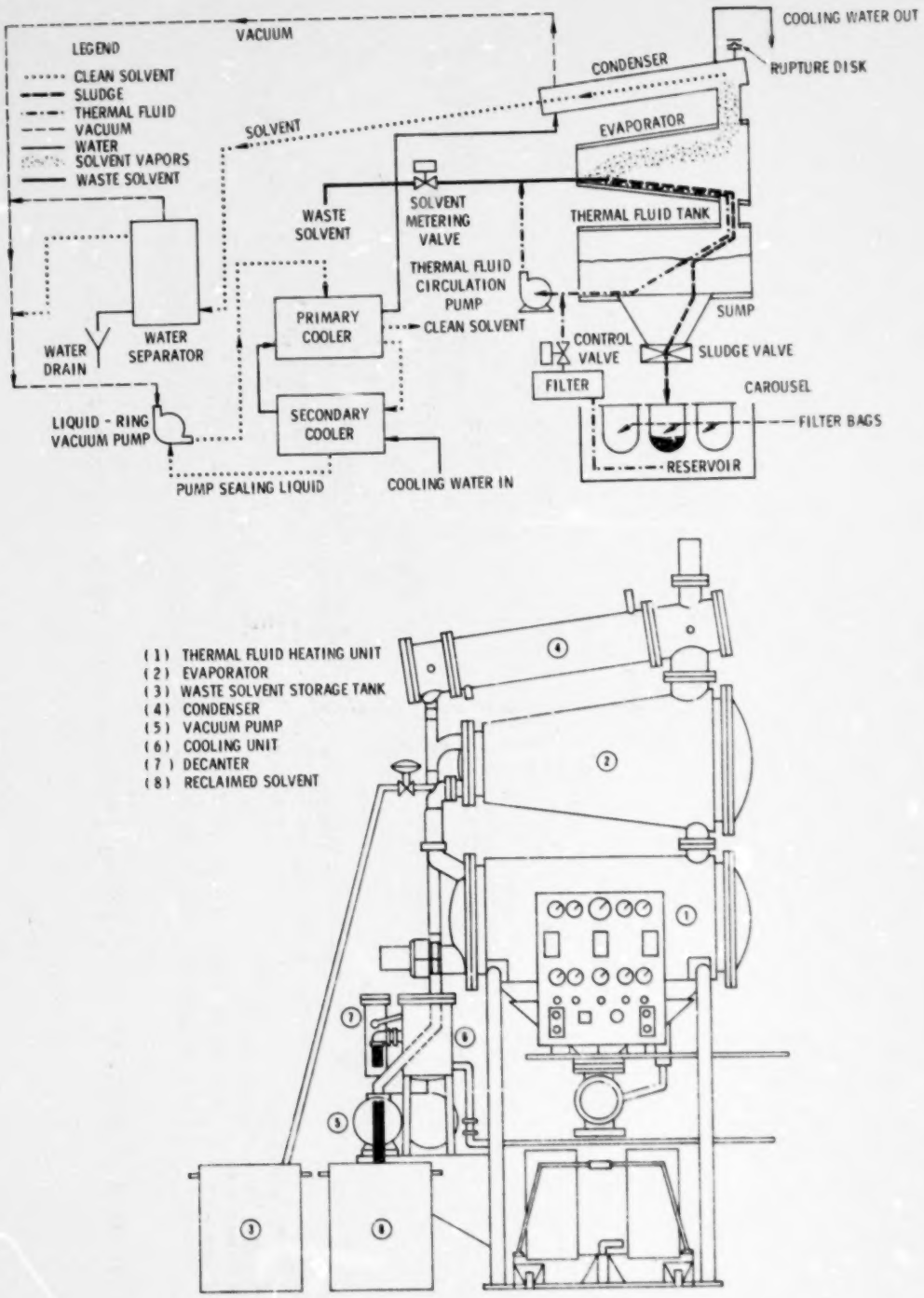
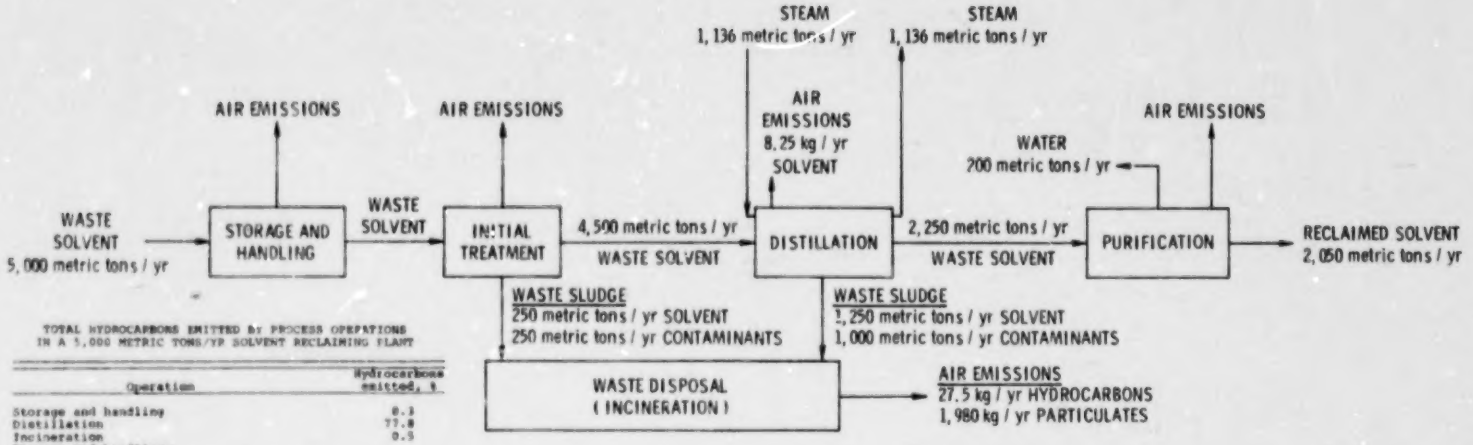


Figure 10. Process schematic and equipment diagram of a solvent recovery unit (30, 31).



TOTAL HYDROCARBONS EMITTED by PROCESS OPERATIONS
IN A 5,000 METRIC TONS/YR SOLVENT RECLAIMING PLANT

Operation		Hydrocarbons emitted, %
Storage and handling		0.1
Distillation		77.8
Incineration		0.5
Storage and handling	Fugitive emissions	21.4
Initial treatment		
Purification		

Figure 11. Material balance for the reclaiming of waste solvents.

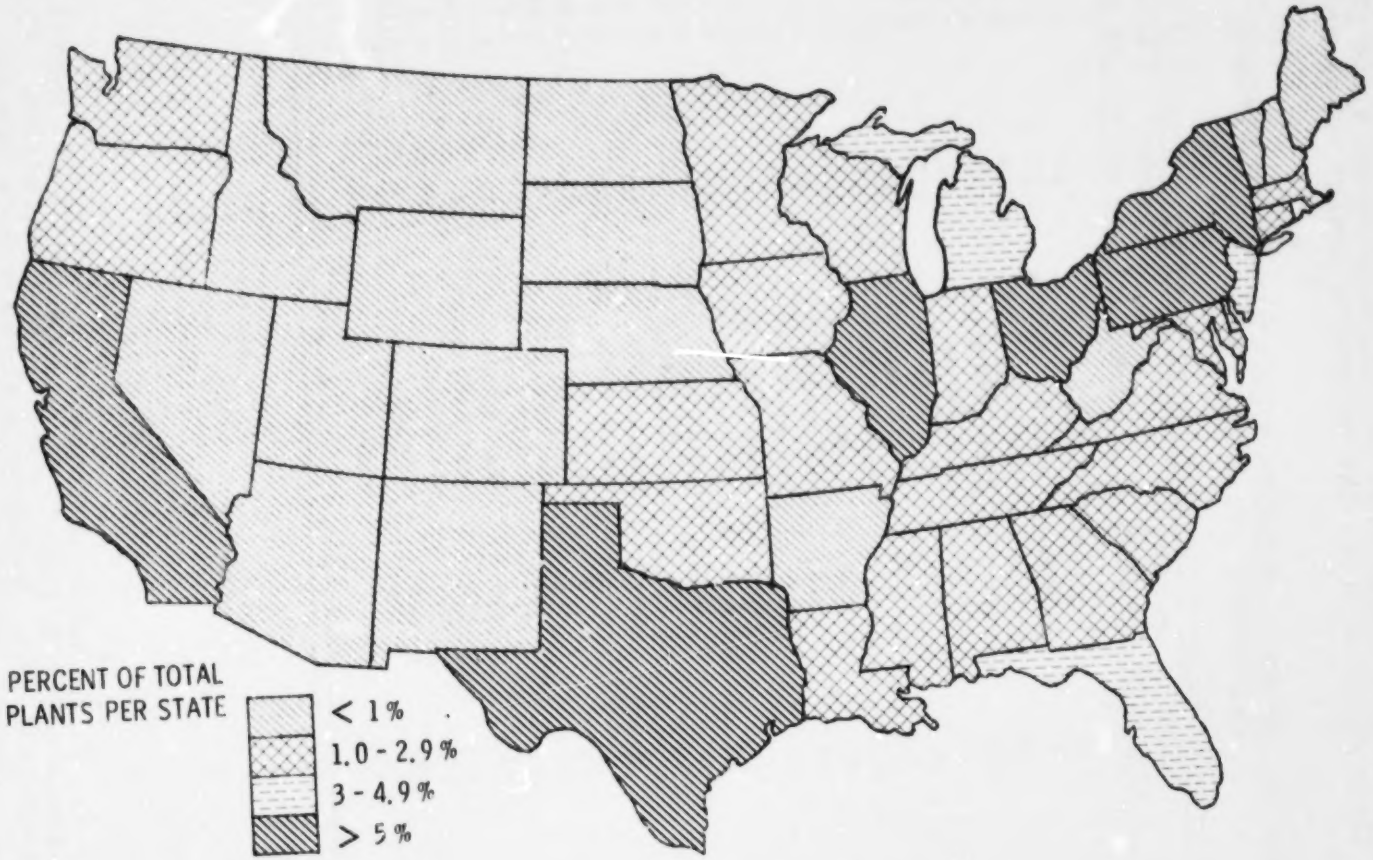


Figure 12. Geographical distribution of solvent reclaiming operations in the United States (2, 9-11, 32).

the other industries given in Table 1 are shown in Figure 12 (2, 9-11, 32). The number of sites in this category, which excludes drycleaning operations, is estimated to be 4,158 plants (2, 9-11, 32). Table 5 gives the estimated number of plants in each state.

TABLE 5. STATE DISTRIBUTION OF SOLVENT RECLAIMING OPERATIONS (2, 9-11, 32)

State	Number of plants	Percent of total	State	Number of plants	Percent of total
Alabama	72	1.8	Nebraska	30	0.77
Arizona	37	0.94	Nevada	10	0.29
Arkansas	39	0.99	New Hampshire	13	0.38
California	424	10.	New Jersey	153	3.7
Colorado	44	0.16	New Mexico	21	0.57
Connecticut	60	1.5	New York	372	8.9
Delaware	12	0.35	North Carolina	105	2.5
Florida	141	3.5	North Dakota	13	0.37
Georgia	98	2.4	Ohio	213	5.1
Idaho	14	0.4	Oklahoma	56	1.3
Illinois	224	5.5	Oregon	40	1.1
Indiana	113	2.8	Pennsylvania	245	5.9
Iowa	59	1.4	Rhode Island	21	0.57
Kansas	49	1.2	South Carolina	55	1.3
Kentucky	70	1.7	South Dakota	13	0.36
Louisiana	83	2.0	Tennessee	83	2.0
Maine	19	0.5	Texas	242	5.8
Maryland	83	2.0	Utah	21	0.56
Massachusetts	85	2.0	Vermont	8	0.24
Michigan	178	4.3	Virginia	97	2.3
Minnesota	76	1.8	Washington	72	1.7
Mississippi	45	1.1	West Virginia	41	0.99
Missouri	98	2.3	Wisconsin	90	2.2
Montana	15	0.41	Wyoming	6	0.14
			TOTAL	4,158	100

(32) Marn, P. J., T. J. Hoogheem, D. A. Horn, and T. W. Hughes. Source Assessment: Solvent Evaporation - Degreasing. Contract 68-02-1874, U.S. Environmental Protection Agency, Cincinnati, Ohio. (Final document submitted to the EPA by Monsanto Research Corporation, January 1977.) 180 pp.

SECTION 4

EMISSIONS

Air emissions from a typical solvent reclaiming operation are described in this section. Criteria pollutants emitted from solvent reclaiming operations include hydrocarbons and particulates. Emissions and their locations were shown earlier in Figure 1. Emissions from solvent storage, distillation, and waste disposal are discussed, and possible fugitive emission points in the solvent reclaiming process are described.

SELECTED POLLUTANTS

Solvent Storage

The storage of solvents results in hydrocarbon emissions from solvent evaporation. Fixed-roof storage tanks are equipped with vents that emit hydrocarbon vapors during solvent storage. Since tanks are continually in use during processing, solvent storage is considered a continuous source of emissions.

Distillation

The venting of gases from distillation units occurs during condensation of solvent vapors. When steam ejectors are used to produce a vacuum in the distillation unit, condensers emit steam, noncondensables, and solvent vapors. The use of pumps for vacuum conditions causes condensers to emit solvent vapors and noncondensables. Hydrocarbons emitted from condensers are a continuous source of emissions.

Waste Disposal

The combustion of still bottom wastes results in emissions from the incinerator stack. Solid contaminants in the sludge are oxidized and released as particulates along with combustion gases. Unburned hydrocarbons are also emitted with combustion stack gases. Particulates and hydrocarbons from incinerators are a continuous source of emissions.

Fugitive Emissions

Emissions from solvent loading, equipment leaks, solvent spills and open solvent sources are classified as fugitive emissions.

Hydrocarbon emissions from solvent loading and spills are intermittent, while emissions from equipment leaks and open solvent sources are continuous.

When solvent is agitated during loading procedures, it is atomized into droplets which quickly evaporate and are emitted as solvent vapors. Loading of fixed-roof tanks causes displacement of the vapor space inside the tank by fresh solvent. This vapor space contains solvent vapors evaporated during storage which are then emitted to the atmosphere as hydrocarbon emissions. Accidental spillage of solvent during loading procedures also results in hydrocarbon emissions from solvent evaporation, as do process equipment leaks.

Other sources of hydrocarbon emissions include open containers of solvents and sludges. Settling tanks with open tops emit solvent vapors during settling and sludge draw-off. During startup of the distillation process an initial amount of distilled solvent may be drawn off in an open drum to remove residual contamination in the distillation equipment. This procedure constitutes an intermittent source of hydrocarbon emissions. Open sources of fugitive emissions include sludge draw-off and storage from distillation and initial treatment operations. Fugitive solvent emissions can result from all of the unit operations described in Section 3.

It is difficult to obtain accurate data on the contributions of fugitive emissions to the overall emission factor for a solvent reclaiming operation. The amount of fugitive emissions present at a particular plant depends upon plant maintenance, process equipment configuration, and the volatility of reclaimed and waste solvents. Reclaiming a highly volatile solvent such as acetone with poor equipment maintenance or configuration will result in fugitive emissions becoming a major contributor to overall emission factors.

EMISSION FACTORS

Emission factors for the various sources of emissions are given in Table 6. The contributions of criteria pollutants from solvent reclaiming operations to the total national emissions from stationary sources are given in Table 7 (33). Contributions to state emissions are given in Table 8.

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(33) 1972 National Emissions Report; National Emissions Data System (NEDS) of the Aerometric and Emissions Reporting System (AEROS). EPA-450/2-74-012, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1974. 434 pp.

TABLE 6. EMISSION FACTORS FOR SOLVENT RECLAIMING[a]

Source	Criteria pollutant	Emission factor range, g/kg	Emission factor average, g/kg
Storage tank vent[b]	Hydrocarbons	0.002 to 0.004	0.0072 ± 0.0038
Condenser vent	Hydrocarbons	0.26 to 4.17	1.65 ± 1.38
Incinerator stack	Hydrocarbons	0.01[c]	0.01[c]
	Particulates	0.55 to 1.0	0.72 ± 0.61
Fugitive emissions			
Spillage	Hydrocarbons	0.095	0.095
Loading	Hydrocarbons	0.00012 to 0.71	0.36 ± 0.24
Leaks	Hydrocarbons		
Open sources	Hydrocarbons		
TOTAL	Hydrocarbons	0.38 to 5.0	2.1
TOTAL	Particulates	0.55 to 1.0	0.72

[a] Data obtained from state air pollution control agencies and pre-survey sampling. All emission factors are for uncontrolled process equipment except those for the incinerator stack. Blanks indicate data not available.

[b] Storage tank is of the fixed-roof design.

[c] Only one value available.

TABLE 7. CONTRIBUTION OF CRITERIA POLLUTANTS FROM SOLVENT RECLAIMING TO NATIONAL STATIONARY SOURCE EMISSIONS[a]

Criteria pollutant	Total national emissions (33), metric tons/yr	Emissions from solvent reclaiming, metric tons/yr	Percent of national emissions
Hydrocarbons	25×10^6	218,000	0.87
Particulates	18×10^6	73,000	0.41

[a] Data derived from material balance.

TABLE 8. SOLVENT RECLAIMING CONTRIBUTIONS TO STATE EMISSIONS OF CRITERIA POLLUTANTS[a]

State	Hydrocarbons			Particulates		
	State emissions, 10^3 metric tons/yr	Emissions from solvent reclaiming, metric tons/yr	Percent of state emissions	State emissions, 10^3 metric tons/yr	Emissions from solvent reclaiming, metric tons/yr	Percent of state emissions
Alabama	643.4	3.9	0.0006	1,179	1.3	0.0001
California	2,161	21.8	0.001	1,010	7.5	0.0007
Connecticut	219.7	3.3	0.0015	40.07	1.1	0.0027
Florida	619.9	7.6	0.0012	226.5	2.6	0.0011
Georgia	458	5.2	0.0011	404.6	1.8	0.0044
Illinois	1,826	12.0	0.0007	1,143	4.1	0.0003
Indiana	600.5	6.1	0.0001	748.4	2.1	0.0003
Iowa	316.6	3.0	0.0094	216.5	1.0	0.0005
Kansas	309.6	2.6	0.0008	348.3	0.89	0.0002
Kentucky	26.3	3.7	0.014	546.2	1.3	0.0002
Louisiana	1,920	4.3	0.0002	380.6	1.5	0.0004
Maryland	295.9	4.3	0.0015	494.9	1.5	0.0003
Massachusetts	440.5	4.3	0.001	96.16	1.5	0.0015
Michigan	717.9	9.3	0.0013	705.9	3.2	0.0005
Minnesota	1,761	3.9	0.0002	266	1.3	0.0004
Mississippi	196	2.4	0.0012	168.3	0.82	0.0005
Missouri	413.1	5.0	0.0012	202.4	1.7	0.0008
New Jersey	819.5	8.1	0.001	151.8	2.8	0.002
New York	1,262	19	0.0015	160	6.6	0.0041
North Carolina	447.2	5.4	0.0012	481	1.9	0.0004
Ohio	1,153	11.0	0.0009	1,766	3.8	0.0002
Oklahoma	341.3	2.8	0.0008	93.6	0.97	0.001
Oregon	234.7	2.4	0.001	169.4	0.82	0.0005
Pennsylvania	891.8	13	0.0015	1,811	4.4	0.0002
South Carolina	907.8	2.8	0.0003	198.8	0.97	0.0005
Tennessee	362.9	4.3	0.0012	409.7	1.5	0.0003
Texas	2,219	13	0.0006	549.4	4.3	0.0008
Virginia	369.4	5.0	0.0013	477.5	1.7	0.0003
Washington	344.6	3.7	0.001	161.9	1.3	0.0008
Wisconsin	523.9	4.8	0.0009	411.6	1.6	0.0004

[a]States where solvent reclaiming operations comprise ≤1.0% of the total number of known reclaiming operations are not considered.

DEFINITION OF A REPRESENTATIVE SOURCE

A representative plant reclaiming waste solvents is defined in order to determine source severity. The population density for a representative plant was determined from data on the locations of private contractors reclaiming waste solvents. Population data for 30 randomly selected plants are given in Table 9. Production capacity for a representative plant was determined

TABLE 9. POPULATION DENSITIES FOR RANDOMLY SELECTED PLANTS RECLAIMING WASTE SOLVENTS[a]

Plant	Location	Population density, persons/km^2
Dyna-Clean Labs	Phoenix, AR	40.8
Rho-Chem	Inglewood, CA	668.1
Davis Chemical	Los Angeles, CA	668.1
Solvent Distilling Service	San Jose, CA	316.7
Solvent Recovery Service	Southington, CT	426.7
Ansec Chemical	Douglasville, GA	54.8
Rho-Chemical	Joliet, IL	23.7
Midwest Solvent Recovery	Chicago, IL	2,223.5
American Chemical Services	Griffith, IN	411.1
Hammond Solvent Recovery Service	Hammond, IN	411.1
Galaxy Chemicals	Elkton, MD	56.8
Silvesim Chemical	Lowell, MA	654.0
Gold Shield Solvents	Detroit, MI	1,704.2
Chemical Recovery Systems	Romulus, MI	1,704.2
Clayton Chemicals	St. Louis, MO	736.4
Marisol	Middlesex, NJ	722.5
C.P.S.	Old Bridge, NJ	722.5
Frontier Chemical Waste Processing	Niagara Falls, NY	171.1
Hukill Chemical	Cleveland, OH	1,457.1
Systech Waste Treatment	Franklin, OH	31.4
Jones Chemical Reclaiming	Erie, PA	126.8
Jadco	Greenville, SC	117.4
Mid-State Solvent Recovery	LeVerque, TN	25.2
Nuclear Sources and Services	Houston, TX	390.3
Western Processing	Seattle, WA	210.4
North Central Chemical	Madison, WI	93.5
Romie Chemical	Palo Alto, CA	565.3
Custom Organics	Chicago, IL	2,223.5
Perk Chemical	Elizabeth, NJ	2,036.0
Chemical Recycling	Wyllie, TX	596.8
	Mean value (95% confidence limit)	653 $\pm$ 212.6

[a]Thirty private contractor sites were selected at random in order to determine mean population.

by taking the total amount of solvent reclaimed by private contractors averaged over the number of sites. Emission height data available from plant visits and presurvey sampling of private contractors are shown in Table 10.

TABLE 10. EMISSION HEIGHT DATA FOR PRIVATE CONTRACTORS RECLAIMING WASTE SOLVENTS

Emission point	Height, m	
Storage tank vent	9.1	
	3.7	
	12.2	
	12.2	
	12.2	
	12.2	
	9.1	
	9.1	
	7.3	
	7.3	
	7.9	
	7.9	
	mean (95% confidence limit)	9.2 ± 1.6
Condenser vent	5.5	
	7.6	
	6.1	
	3.7	
	9.1	
	mean (95% confidence limit)	6.4 ± 2.6
Incinerator stack	18.3	18.3[a]
Fugitive emissions	2.4	2.4[a]

[a]Only one numerical value available.

Emission factors from Table 6 were used for a representative plant. Table 11 summarizes the data for a representative plant.

ENVIRONMENTAL EFFECTS

Maximum Ground Level Concentration

The maximum ground level concentration, χ_{max}, for materials emitted by solvent reclamation was estimated by Gaussian plume dispersion theory.

Time-Averaged Maximum Ground Level Concentration

The maximum ground level concentration averaged over a given period of time, $\bar{\chi}_{max}$, is calculated from χ_{max} by the following equation:

TABLE 11. SUMMARY OF DATA FOR A REPRESENTATIVE PLANT

Parameter	Value for representative plant
Process	Solvent reclaiming
Raw material	Waste solvent
Population density, persons/km^2	653 ± 33%
Production capacity, metric tons/yr	1,737 ± 30%
Emission heights, m	
Storage tank vent	9.2 ± 17%
Condenser vent	6.4 ± 41%
Incinerator stack	18.3
Fugitive emissions	2.4
Emission factor, g/kg	
Storage tank vent	0.0072 ± 53%
Condenser vent	1.65 ± 84%
Incinerator stack	
Particulates	0.72 ± 84%
Hydrocarbons	0.01
Fugitive emissions	0.455

$$\bar{\chi}_{max} = \chi_{max}\left(\frac{t_o}{t}\right)^{0.17} \quad (1)$$

where t = averaging time, min
t_o = short-term averaging time, <3 min

The averaging times for particulates and hydrocarbons are 24 hr and 3 hr, respectively.

Source Severity

The hazard potential of solvent reclaiming operations can be quantified by determining a source severity, S, which is defined as the ratio of the time-averaged maximum ground level concentration to F, the hazard exposure level for a pollutant. Since only criteria pollutants are being considered at this point, the primary ambient air quality standards for hydrocarbons and particulates represent the hazard exposure level, F. The source severity is thus calculated in the following manner:

$$S = \frac{\bar{\chi}_{max}}{F} \quad (2)$$

Table 12 gives the emission rate, maximum ground level concentration, time-averaged maximum ground level concentration and source severity of the emission points described in this section for a representative solvent reclaiming plant.

TABLE 12. EMISSION RATE, χ_{max}, $\overline{\chi}_{max}$ AND SOURCE SEVERITY FOR EMISSIONS FROM A REPRESENTATIVE SOLVENT RECLAIMING PLANT

Emission point	Emission rate, g/s	χ_{max}, g/m^3	$\overline{\chi}_{max}$, g/m^3	Source severity
Storage tank vent	0.0004	2.5×10^{-7}	1.2×10^{-7}	0.00075
Condenser	0.09	1.1×10^{-4}	5.5×10^{-5}	0.34
Incinerator stack				
Particulates	0.04	6.3×10^{-6}	2.2×10^{-6}	0.0085
Hydrocarbons	0.0005	7.8×10^{-8}	3.9×10^{-8}	0.00024
Fugitive emissions	0.03	2.7×10^{-4}	1.3×10^{-4}	0.84

The source severity for total hydrocarbons emitted by a representative solvent reclaiming plant has been calculated. A mean emission height of 8.6 ± 1.8 m was used with a total hydrocarbon emission rate of 0.12 g/s. Table 13 gives the results of this calculation.

TABLE 13. SOURCE SEVERITY FOR TOTAL HYDROCARBONS EMITTED FROM A REPRESENTATIVE PLANT (UNCONTROLLED EMISSIONS)

Emission	Emission rate, g/s	χ_{max}, g/m^3	$\overline{\chi}_{max}$, g/m^3	Source severity
Hydrocarbons	0.12	1.0×10^{-4}	5.0×10^{-5}	0.31

Table 14 lists threshold limit values (TLV®) (34) for commonly reclaimed solvents. Source severities for selected solvents are shown in Table 15.

Affected Population

The population affected by a solvent reclaiming operation is determined from representative plant data. Since no source severity greater than 1.0 was determined, the population affected by a source severity greater than 0.1 was utilized. Table 16 gives the affected population when $\overline{\chi}/F > 0.1$ over an area of 0.12 km^2. This affected population was obtained by calculating the area within the isopleth for $\overline{\chi}_{max}$.

(34) TLVs® Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1976. American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1976. 97 pp.

TABLE 14. THRESHOLD LIMIT VALUES FOR SELECTED SOLVENTS

Solvent	TLV, mg/m^3
Acetone	2,400
Amyl acetate	650
Benzene	80
Butanol	300
Cyclohexane	1,050
Ethyl acetate	1,400
Ethanol	1,900
Hexane	1,800
Isopropanol	980
Methyl ethyl ketone	590
Methyl isobutyl ketone	410
Methylene chloride	360
Perchloroethylene	670
Toluene	375
1,1,1-Trichloroethane	1,900
Trichloroethylene	535
Xylene	435

TABLE 15. SOURCE SEVERITY FOR SELECTED SOLVENTS[a]

Solvent	TLV, g/m^3	$\bar{\chi}_{max}$, g/m^3	Source severity
Acetone	2.4	5.0×10^{-5}	0.0063
Isopropanol	0.98	5.0×10^{-5}	0.015
Methyl ethyl ketone	0.59	5.0×10^{-5}	0.026
Toluene	0.37	5.0×10^{-5}	0.042
Butanol	0.3	5.0×10^{-5}	0.05

[a]Data for emission rate, χ_{max}, and $\bar{\chi}_{max}$ were taken from Table 12.

TABLE 16. AFFECTED POPULATION FOR A REPRESENTATIVE PLANT (UNCONTROLLED EMISSIONS)

Parameter	Value for representative plant
Population density, persons/km^2	653
Emission height, m	8.6
Emission rate, g/s	0.12
Pollutant type	hydrocarbons
Source severity	0.31
Affected area, km^2	0.12
Affected population, persons	78

SECTION 5

CONTROL TECHNOLOGY

STATE OF THE ART

Solvent reclamation is viewed by industry as a form of control technology in itself. For industries where hydrocarbons are emitted, such as in ink printing operations, reclaiming of solvent vapors provides a means of emission control while recovering a valuable production material (19). In this case the cost of control technology is defrayed by the value of recovered solvent. Reclamation of liquid waste solvents is also a form of control technology since their disposal rather than reuse would cause additional emissions to the atmosphere.

Control technology is described below for three areas of solvent reclaiming operations: storage and handling, distillation, and waste disposal. The number of plants that employ control technology is not known. Estimates have been given that less than 50% of the plants run by private contractors utilize control technology (9).

Hydrocarbon emissions from the storage of solvents are reduced by improved storage tank design. Floating-roof tanks emit 94% to 98% less hydrocarbons by weight, as compared to fixed-roof designs, by reducing the available surface area of stored solvent exposed to air and by eliminating vapor space between the solvent surface and storage tank roof (35). Reduction of hydrocarbon emissions by a floating-roof tank is dependent upon solvent evaporation rate, ambient temperature, loading rate, and tank capacity.

Control technology may be added to fixed-roof tanks to reduce hydrocarbon emissions from stored solvents. Tanks are refrigerated to reduce emissions by decreasing the evaporation rate of the stored solvent. Conservation vents are also used to control emissions from stored solvent. These vents are equipped with breather valves designed to prevent either the inflow of air or the escape of vapors from the tank until some preset vacuum or

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(35) Manual on Disposal of Refinery Wastes, Volume on Atmospheric Emissions. American Petroleum Institute, Washington, D.C., February 1976. pp. 7-1 through 7-14.

pressure develops (36). This system prevents stored solvent from contact with the atmosphere unless the tank is being filled or drained of solvent.

Submerged filling of storage tanks and tank cars, rather than splash filling, can reduce solvent emissions by more than half (35). Submerged filling minimizes agitation and atomization of liquid solvent when it is pumped into the tank.

Proper plant maintenance and loading procedures reduce solvent emissions from leaks and spills. Fugitive emissions from process equipment leaks pose a problem not only as air pollutants but also as a safety hazard, especially when reclaiming flammable solvents. Leaks can be controlled by replacing worn-out equipment and performing regular maintenance procedures. Careful loading procedures can reduce the number of solvent spills and consequent emissions from spilled solvent evaporation.

Solvent vapors vented during distillation are controlled by scrubbers and additional condensers. A countercurrent packed scrubber has been used to control vent gases from solvent distillation. In this type of unit vent gases enter from the bottom and travel up through the scrubber, which is filled with packing material. An absorbing liquid enters the scrubber from the top and passes through concurrently to the flow of vent gases. Contact between absorbing liquid and vent gases occurs in the packed section of the scrubber. Gases not absorbed by the liquid are released to the atmosphere from the top of the scrubber. One private contractor reclaiming waste solvents reported a 99% control efficiency for a gas scrubber installed in line with condenser vents. In Figure 13, a packed scrubber is shown (37).

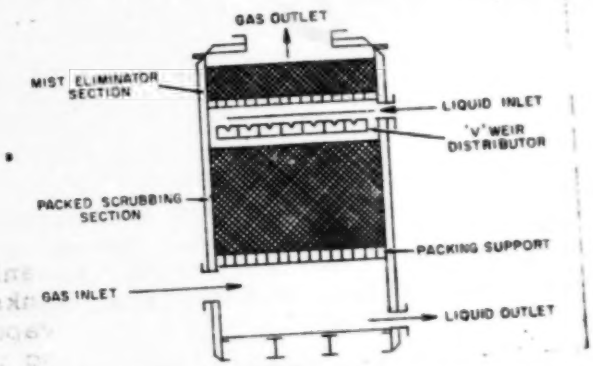

Figure 13. Typical countercurrent vent gas scrubber (37).

(36) Evaporation Loss in the Petroleum Industry - Causes and Control. Bulletin No. 25B, American Petroleum Institute, Washington, D.C., 1959. 59 pp.

(37) Liptak, B. G. Environmental Engineer's Handbook, Vol. 2. Chilton Book Company, Radnor, Pennsylvania, 1974. 1340 pp.

Solvent vapors vented by the condenser during distillation are also reduced by addition of a secondary condenser in series with the first. Vent gases are condensed in the secondary condenser to yield distilled solvent which had passed through the primary condenser.

Afterburners can be used to control noncondensables and solvent vapors not condensed during distillation. Two types of afterburners used to control solvent vapors are direct flame and catalytic. The time necessary for complete combustion of solvent vapors by an afterburner will depend on the flammability of the solvent. For most solvents 0.3 s to 0.6 s at 1,193°C to 1,306°C is required for effective control of vent gases (38). Condenser emissions have also been controlled with the afterburner principle by venting gases to a boiler firebox where they are combusted (39).

Control of vent gases in the manufacture of vegetable oils has been accomplished by refrigerated condenser vents or the addition of vapor control devices utilizing carbon adsorption or oil adsorption (40).

In wet scrubbers, which are used to remove particulates from incinerator exhaust gases, gas flow is constricted by a venturi throat where water is atomized to remove particulates by impaction. Submicron particulates are not effectively controlled by wet scrubbers. One plant reclaiming wastes solvents reported metal oxide emissions from their incinerator stack after gas stream scrubbing (9).

Source severity for a representative plant with control equipment is shown in Table 17.

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(38) Control Techniques for Hydrocarbon and Organic Solvent Emissions from Stationary Sources. National Air Pollution Control Administration Publication No. AP-68, U.S. Department of Health, Education, and Welfare, Washington, D.C., March 1970. 1-1 to 7-3 pp.

(39) Air Pollution Engineering Manual, Second Edition, J. A. Danielson, ed. Publication No. AP-40, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1973. 987 pp.

(40) Background Information for Establishment of National Standards of Performance for New Sources, Vegetable Oil Industry (Draft). Contract CPA 70-142, Task 9h, U.S. Environmental Protection Agency, Raleigh, North Carolina, July 1971. 64 pp.

TABLE 17. SOURCE SEVERITIES FOR RECLAIMING PLANTS WITH AND WITHOUT CONTROL EQUIPMENT[a]

Control equipment used	Source severity[b]
None	0.31
Floating-roof storage tanks	0.23
Vent gas scrubber	0.12
Floating-roof storage tank and vent gas scrubber	0.082
Submerged loading	0.22

[a]Data from a representative plant and control equipment efficiencies were used to calculate source severity.

[b]All source severities refer to total hydrocarbons emitted from a representative plant. Calculation of these source severities is the same as that used in Table 13. Values shown represent the source severity for total hydrocarbons when various control equipment is utilized. Values should not be compared with source severities in Table 12 as they are for specific uncontrolled emission points at various heights.

FUTURE CONSIDERATIONS

Due to the increase in the price of virgin solvent, industry will strive for increased efficiencies when reclaiming solvents (9). Operations reclaiming up to 4.5×10^6 metric ton/yr of solvent must achieve recovery efficiencies of greater than 90% if capital losses from solvent consumption are to be avoided (3). Improved efficiency of recovery operations stimulated by the higher costs of solvents will serve as a means of emission reduction. Also, federal, state, and local emission standards for hydrocarbons are becoming increasingly stringent (41).

The cost of disposal for waste from solvent reclaiming has more than doubled in the past 5 years. This has been caused by the increasing scarcity of acceptable landfill sites and the imposition of emission regulations on the disposal of liquid wastes by incineration. As an alternative to disposal, new applications for reclaimed solvent wastes are being tried. One application is the use of reclaiming wastes as asphalt extenders and concrete block fillers (9). At a paint manufacturing plant, wastes from spent solvent reclamation are reused in the main paint production process (42).

(41) Teale, J. M. Fast Payout From In-Plant Recovery of Spent Solvents. Chemical Engineering, 84(3):98-100, 1977.

(42) Emmerling, J. Economical Recovery of Waste Solvent Provided by System. Chemical Processing, 38(4):22-24, 1975.

SECTION 6

GROWTH AND NATURE OF THE INDUSTRY

PRESENT TECHNOLOGY

Technology for the reclaiming of waste solvents is well established (9). The operations described in this document will continue to be used for all aspects of solvent reclaiming.

EMERGING TECHNOLOGY

Though solvent reclaiming technology is well established, collection of waste solvent vapors and liquids is not always economically or technically feasible. Established plants emitting waste solvents were not designed with vapor collection in mind. These plants find that the cost of installing present-day venting systems is prohibitive or that the systems are not capable of collecting a major portion of the solvent vapors emitted. New plants where waste solvents are produced from solvent usage will be designed with solvent collection and reclamation as part of the main process. Small plants using only 500 kg/day of solvent find on-site solvent reclamation uneconomical in terms of manpower and equipment needs. Recent engineering estimates, however, have shown that small on-site reclaiming systems can cover installation and operating costs through the value of the reclaimed solvent (41).

Design parameters and economic factors are considered in determining whether an on-site reclaiming system is a worthwhile venture for a particular plant. The size of the distillation unit, steam requirements, and manpower needs can be calculated from the type and amount of solvent used during plant operation. Knowledge of the physical and chemical properties of contaminants which are removed from the waste solvent during reclamation is also important. Design of the distillation unit, cost of materials on its construction, and percentage of solvent recovered are determined by the extent and characterization of contamination present in the waste solvent. These considerations will influence the decision as to whether a waste solvent is more economically reclaimed on site, recovered by a private contractor or simply disposed of by landfilling or incineration.

Waste solvents reclaimed from a paint manufacturing operation results in highly corrosive and viscous stillbottoms. Corrosive-resistant materials must be employed in the construction of the

distillation apparatus to insure a reasonable period of use from the equipment. The percentage of solvent recovered from the waste solvent is about 40% to 50%. If more solvent was distilled off, the stillbottoms would present an additional handling and disposal problem due to their increasingly high viscosity.

At a printing operation, however, 80% of the waste solvent can be recovered with a distillation unit of lower material standards. Ink contaminants are less corrosive to materials used in the distillation apparatus. Recovery of a greater percentage of solvent is also possible since the resulting stillbottoms are less viscous than those produced from the reclamation of solvents used in paint manufacturing.

When investigating the feasibility of on-site solvent reclamation by a particular plant, reviewing alternatives based on economy is necessary. Differences in the cost of virgin solvent utilization, waste solvent disposal, private contractor reclamation, and on-site reclamation become important criteria in determining the practicality of any solvent reuse scheme.

INDUSTRY PRODUCTION TRENDS

Growth rates for solvent reclaiming operations depend upon the rate of growth of solvent usage. In industries such as solvent refining and vegetable oil extraction, where solvent recovery is well established, the growth of solvent reclaiming will follow the growth of the industry itself. For industries such as coating applications and degreasing operations, where solvent recovery is not consistent throughout all plants, the growth of solvent reclamation will be governed by solvent availability and cost. A growth rate for private contractors has been estimated at a 5% increase annually in the amount of solvent reclaimed (9). It is expected that the growth of solvent reclaiming operations will follow the growth of future solvent usage. Table 18 gives expected growth rates for solvent usage through 1980 (14).

TABLE 18. GROWTH RATES FOR SELECTED SOLVENTS (14)
(Percent)

Solvent	1975 to 1980
Ketones	0.2
Esters	0.7
Glycol-ethers	1.9
Amyl, butyl, ethyl and isopropyl alcohols	0.7
Methyl chloride	3.5
Methylene chloride	6.0
Chloroform	9.0
Carbon tetrachloride	3.4
Trichlorethylene	1.3
1,1,1-Trichloroethane	7.5

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APPENDIX A

NAMES AND LOCATIONS OF PRIVATE CONTRACTORS RECLAIMING WASTE SOLVENTS IN THE UNITED STATES

Table A-1 lists private U.S. contractors engaged in solvent recovery.

TABLE A-1. PLANTS ENGAGED IN SOLVENT RECOVERY AS PRIVATE CONTRACTORS[a]

State	Plant
Arizona	Dyna-Clean Labs, Phoenix
	Fluid Conditioning Co., Phoenix
	Western Oil Co., Phoenix
	Southwest Solvents, Phoenix
California	RHO-CHEM, Inglewood
	James B. Bachelor Co., Whittier
	Baron Blakeslee, Belmont
	Chem-Serv., Pinedale
	Davis Chemical Co., Los Angeles
	Gold Shield Solvents, Los Angeles
	Oil and Solvent Process, Azusa
	Romie Chemical Corp., Palo Alto
	Solvent Distilling Serv., San Jose
	Bateman Chemicals, San Diego
	Zero Waste Systems, San Francisco
Colorado	Mountain Chemicals, Denver
Connecticut	Solvent Recovery Service, Southington
Delaware	Aldorado Chemical Services, Wilmington
Florida	Gold Coast Oil Corp., Miami
	City Chemicals, Orlando
Georgia	Arisec Chemical Co., Douglasville
	M and J Solvents Co., Atlanta
Illinois	Acme Solvent Reclaiming Inc., Rockford
	Fisher-Calo Chemicals and Solvent Co., Chicago
	Rho Chemical Co., Joliet

[a]Data obtained from industry contacts and Reference 9.

(continued)

TABLE A-1 (continued).

State	Plant
Illinois	Custom Organics, Chicago
	Refining Products Division, Chicago
	Syn-Sol Corp., Chicago
	Midwest Solvent Recovery Co., Chicago
	Crest Chemical Services, Inc., Chicago
	American Ceca Corp., Oakbrook
	Barker Chemical Co.
Indiana	American Chemical Services, Griffith
	Seymour Manufacturing Co., Seymour
	Conservation Chemical Co., Indianapolis
	Hammond Solvents Recovery Service, Hammond
	Inland Chemical Corp., Fort Wayne
Kansas	Chemical Commodities, Olathe
Kentucky	George Whitesides, Louisville
	Inland Chemical, New Castle
Maryland	Galaxy Chemicals, Inc., Elkton
	Browning-Ferris, Baltimore
Massachusetts	Montvale Laboratories, Stoneham
	Re-solve, Inc., New Bedford
	Silvesim Chemical Corp., Lowell
	Marylin Engineering Corporation, Boston
	Cannons Engineering Corp., Boston
	Mancor Chemical and Equipment Co., Boston
Michigan	Gold Shield Solvents, Detroit
	Gold Shield Solvents, Grand Rapids
	Organic Chemicals, Grand Rapids
	Nelson Chemicals, Detroit
	Thomas Solvent Co., Detroit
	Chemical Recovery Systems, Inc., Romulus
	U.S. Chemical Co., Detroit
	Spartan Chemical Co., Grand Rapids
Missouri	Conservation Chemical Co., Kansas City
	Clayton Chemicals, St. Louis
New Jersey	National Converters
	General Scientific
	Gold Shield Solvents, Riverton
	Hogan Solvents and Chemicals, Kearny
	Marisol Inc., Middlesex
	Perk Chemical Co., Elizabeth
	Scientific Chemical Processing, Carlstadt
	Solvent Recovery Service, Linden
	C.P.S., Old Bridge
	Swope Oil and Chemical Co., Pennsauken

(continued)

TABLE A-1 (continued).

State	Plant
New York	Bell Chemical Co., Long Island Chemical and Solvent Distillers, Astoria Chem-Trol Pollution Services, Model City Recycling Laboratories, Syracuse Ajax Chemical Corp., Floral Park Aceto Chemical Co., Flushing Frontier Chemical Waste Processing Co., Niagara Falls
North Carolina	Gold Shield Solvents, Charlotte Seaborg Chemical, Jamestown
Ohio	Chemical Solvent Inc., Cleveland Chemtron Corp., Avon Hukill Chemical Corp., Cleveland Chemical Recovery Systems, Elyria Spray-Dyne Corp., Fernald Klor Kleen, Inc., Cincinnati Systech Waste Treatment, Franklin
Oregon	Chempro of Oregon, Portland Spe-de-Way Products Co., Portland
Pennsylvania	Tri State Chemicals, Inc., Philadelphia Jones Chemical Reclaiming, Erie Roberts Solvent Co., Philadelphia
Rhode Island	Colonial Chemical Co., Johnstown G. M. Gannon Co., Inc., Warwick
South Carolina	Jadco Corp., Greenville Groce Laboratories, Greer
Tennessee	George Mills Industries, Nashville G-M Solvent and Material Recycling, Nashville Mid-State Solvent Recovery, LaVergne
Texas	Chemical Recycling Inc., Willie Western States Refining co., Dallas Lortep Laboratories, Inc., Houston Nuclear Sources and Services, Houston Emchem Corp., Houston Chemet Corp., Houston
Washington	Chemical Processors, Inc., Seattle Western Processing Co., Seattle Seattle Chemical Co., Seattle
Wisconsin	Milwaukee Solvents and Chemicals, Menom Falls Rogers Laboratories, Milwaukee Waste Research and Reclamation Co., Eau Claire North Central Chemical, Inc., Madison Commerce Industrial Chemicals, Milwaukee

APPENDIX B

RESULTS AND SAMPLE CALCULATIONS FOR PRESURVEY SAMPLING AT A PRIVATE CONTRACTOR SOLVENT RECLAIMING PLANT[a]

Air emissions from a condenser vent at a solvent reclaiming plant were sampled for total hydrocarbons in two 1-hr periods. The samples, both in aqueous suspensions, were analyzed for total organic carbon with the following results:

First Run	Sample A	1,295 mg carbon
Second Run	Sample B	1,977 mg carbon

An emission factor was calculated in grams of hydrocarbons emitted per kilogram of solvent reclaimed, using the following data:

Sample A Composition:
- 1,295 mg carbon
- 100 mℓ distilled H_2O
- 33.6 mℓ process steam
- 699 kg solvent/hr reclaimed
- 2.27×10^4 mℓ process steam/hr utilized

First, total hydrocarbons (HC) were calculated by converting the mass of carbon to an equivalent mass of methane (CH_4):

$$\left(\frac{1.298 \text{ g carbon}}{1}\right)\left(\frac{1 \text{ mole carbon}}{12.011 \text{ g carbon}}\right)\left(\frac{1 \text{ mole } CH_4}{1 \text{ mole carbon}}\right)\left(\frac{16.043 \text{ g } CH_4}{1 \text{ mole } CH_4}\right)$$

$$= 1.734 \text{ g HC}$$

An emission factor was then calculated using the known amount of solvent reclaimed by the plant over time and the amount of steam utilized by the plant per hour:

$$\left(\frac{1.734 \text{ g HC}}{33.6 \text{ mℓ steam}}\right)\left(\frac{2.27 \times 10^4 \text{ mℓ steam}}{699 \text{ kg reclaimed solvent}}\right) = \frac{1.7 \text{ g HC}}{\text{kg reclaimed solvent}}$$

An emission factor of 1.8 g HC/kg reclaimed solvent was determined for Sample B utilizing the above calculations.

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[a] Nonmetric units are used in this appendix since they correspond to those used in presurvey data calculations.

Five storage tanks containing wastes on reclaimed solvents were loaded on site at the plant. Solvent is emitted as a vapor from such tanks during daily ambient temperature changes and loading procedures. Emission factors were determined for these tanks by calculating their breathing and working losses of stored solvent, based on the following equations, which were developed and reported in the referenced API Bulletins (35, 43-45).

Step 1. Calculate the equivalent gasoline breathing loss:

$$L_Y = \frac{24}{1{,}000}\left(\frac{P}{14.7 - P}\right)^{0.68} D^{1.73} (H')^{0.51} (\Delta T)^{0.50} F_P C \qquad \text{(B-1)}$$

where L_Y = equivalent gasoline breathing loss, bbl/yr

P = vapor pressure of material stored at bulk temperature, psia

D = tank diameter, ft

H' = tank outage, ft

ΔT = average ambient temperature change, °F

F_P = paint factor

C = diameter factor

The yearly average bulk temperature of stored solvent was estimated to be 60°F. A vapor pressure for the solvent was estimated by reviewing vapor pressures of selected solvents at 60°F. Tank dimensions were given by plant personnel at the time of sampling. The average ambient temperature change, ΔT, was taken as 19°F, the national average value. The paint factors, F_P, were determined by the outside colors of the tanks. Diameter factors, C, were determined from a graph given in Reference 42; they are between 0.25 and 1.0.

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(43) Evaporation Loss from Fixed Roof Tanks. API Bulletin 2518, American Petroleum Institute, New York, New York, 1962. 38 pp.

(44) Use of Variable Vapor Space Systems to Reduce Evaporation Loss. API Bulletin 2520, American Petroleum Institute, New York, New York, 1964. 14 pp.

(45) Petrochemical Evaporation Loss from Storage Tanks. API Bulletin 2523, American Petroleum Institute, New York, New York, 1969. 14 pp.

Step 2. Calculate the equivalent gasoline working loss:

$$F_g = \frac{3}{10{,}000} PVNK_T \quad \text{(B-2)}$$

where F_g = equivalent gasoline working loss, bbl/yr
V = tank capacity, bbl
N = number of turnovers per year
K_T = turnover factor = 1.0 for $N \leq 36$
$= \frac{180 + N}{6N}$ for $N > 36$

Step 3. Compute total equivalent gasoline loss, L_g:

$$L_g = L_y + F_g \quad \text{(B-3)}$$

Step 4. Compute petrochemical losses:

$$L = 0.08\left(\frac{M}{W}\right)L_g \quad \text{(B-4)}$$

where L = total petrochemical loss, bbl/yr
M = molecular weight of chemical stored
W = liquid density of chemical stored, lb/gal

Step 5. Calculate emission factor:

$$L_l = L(42)(W) \quad \text{(B-5)}$$

$$E' = \frac{L_l}{Cap} \quad \text{(B-6)}$$

$$E = \frac{E'}{2} \quad \text{(B-7)}$$

where L_l = petrochemical loss, lb/yr
Cap = production capacity, ton/yr
E' = emission factor, lb/ton
E = emission factor, g/kg

Table B-1 lists the input data for each storage tank and its calculated emission factor. The number of turnovers for each tank was estimated by noting the plant production capacity and tank size.

TABLE B-1. INPUT DATA AND EMISSION FACTORS FOR FIXED-ROOF STORAGE TANKS AT A SOLVENT RECLAIMING PLANT (PRESURVEY STUDY)

Input Date	1	2	3	4	5
Annual production capacity, tons/yr	4,800	4,800	4,800	4,800	4,800
Average ambient temperature, °F	60	60	60	60	60
Average ambient temperature change, °F	19	19	19	19	19
Molecular weight of stored material, lb/lb-mole	74.20	74.20	74.20	74.20	74.20
Liquid density, lb/gal	7.0	7.0	7.0	7.0	7.0
True vapor pressure at bulk temperature, psia	1.67	1.67	1.67	1.67	1.67
Bulk temperature, °F	60	60	60	60	60
Tank diameter, ft	8.0	8.0	8.0	8.0	11.0
Tank height, ft	18.0	8.0	8.0	8.0	15.0
Paint factor	1.46	1.20	1.2	1.2	1.46
Diameter factor	0.4	0.4	0.4	0.4	0.55
Turnover factor	0.4	0.3	0.4	0.4	0.70
Number of turnovers per year	137	228	137	137	52
Tank capacity, bbl	167	72	72	72	228
Emission factor, g/kg	0.1566	0.0775	0.0648	0.0648	0.1821

A source severity was calculated for the plant from condenser vent and storage tank emission data. To determine source severity, a maximum ground level concentration, χ_{max}, is calculated as follows:

$$\chi_{max} = \frac{2\,Q}{\pi H^2 e \bar{u}} \qquad \text{(B-8)}$$

where Q = mass emission rate, g/s
$\bar{u}$ = average wind speed, m/s
H = effective emission height, m
e = 2.72

$$\chi_{max} = \frac{(2)(0.44)}{(3.14)(6^2)(2.72)(4.5)}$$

$$\chi_{max} = 6.36 \times 10^{-4}$$

The mass emission rate, 0.44 g/s, was determined by the emission factor and plant production capacity. The national average wind speed of 4.5 m/s was used for the average wind speed, $\bar{u}$. The effective emission height for the plant has been given as 6 m.

Since the plant is a continuously emitting source and χ_{max} represents a value for a short-term averaging time (approximately 3 min), a maximum mean ground level concentration, $\bar{\chi}_{max}$ for time intervals between 3 min and 24 hr is estimated:

$$\bar{\chi}_{max} = \chi_{max} \left(\frac{t_o}{t}\right)^{0.17} \qquad \text{(B-9)}$$

where t_o = short-term averaging time (3 min)
t = averaging time, min

Hydrocarbons are a criteria pollutant; the averaging time is therefore 180 min by definition at the primary ambient air quality standard, and:

$$\bar{\chi}_{max} = 6.36 \times 10^{-4} \left(\frac{3}{180}\right)^{0.17}$$

$$\bar{\chi}_{max} = 3.17 \times 10^{-4}$$

Source severity in this case is defined as the ratio of $\bar{\chi}_{max}$ to the primary standard for hydrocarbons, which is 1.6×10^{-4} g/m^3.

$$S = \frac{\bar{\chi}_{max}}{F} \qquad \text{(B-10)}$$

where F = the primary standard for hydrocarbons

$$S = \frac{3.17 \times 10^{-4}}{1.6 \times 10^{-4}}$$

$$S = 1.9$$

Still bottom wastes from the distillation operation were landfilled rather than incinerated. No particulate emissions were evident from the solvent reclaiming operation. The composition of the still bottom wastes is shown in the total in Table 4.

GLOSSARY

affected population: Number of nonplant persons exposed to concentrations of airborne materials which are present in concentrations greater than a determined hazard potential factor.

criteria pollutants: Emission species for which ambient air quality standards have been established; these include particulates, sulfur oxides, nitrogen oxides, carbon monoxide.

emission factor: Weight of material emitted to the atmosphere per unit of produced acrylonitrile, e.g., g material/kg product.

incinerator: Thermal oxidizer used for ultimate disposal of acetonitrile and hydrogen cyanide byproducts and plant residues.

material: Term used in reference to waste in reclaimed solvents.

reflux: Condensed solvent which flows countercurrently to rising solvent vapors in the rectification column during distillation.

sludge: Contaminants which have been separated from solvents during their reclamation.

solvent recovery or reclamation: Process of restoring a waste solvent to a condition where it can be reused by industry.

source severity: Ratio of the maximum mean ground level concentration of emitted species to the hazard factor for the species.

still bottom: Sludge which has been separated from solvents during distillation; usually drawn off from the evaporation.

threshold limit value: Refers to airborne concentrations of substances and represents conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effect (34).

waste solvent: Solvent which has become contaminated through industrial use.